

AD-A147 697

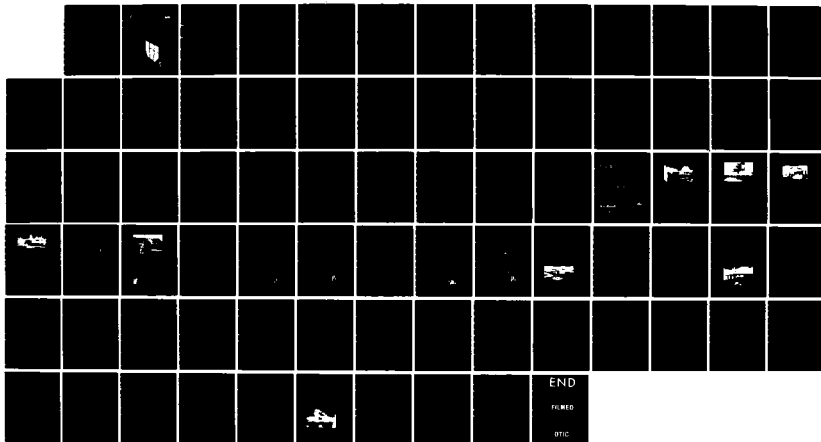
FIELD TEST RESULTS OF EXPERIMENTAL EPDM (ETHYLENE
PROPYLENE DIENE MONOMER. (U) CONSTRUCTION ENGINEERING
RESEARCH LAB (ARMY) CHAMPAIGN IL M J ROSENFELD SEP 84
CERL-TR-M-357

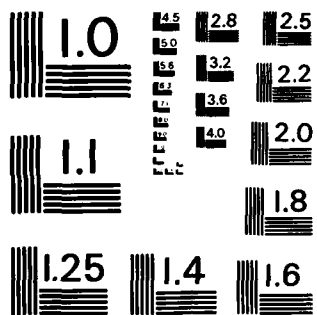
1/1

UNCLASSIFIED

F/G 13/13

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A147 697



**US Army Corps
of Engineers**

Construction Engineering
Research Laboratory

12

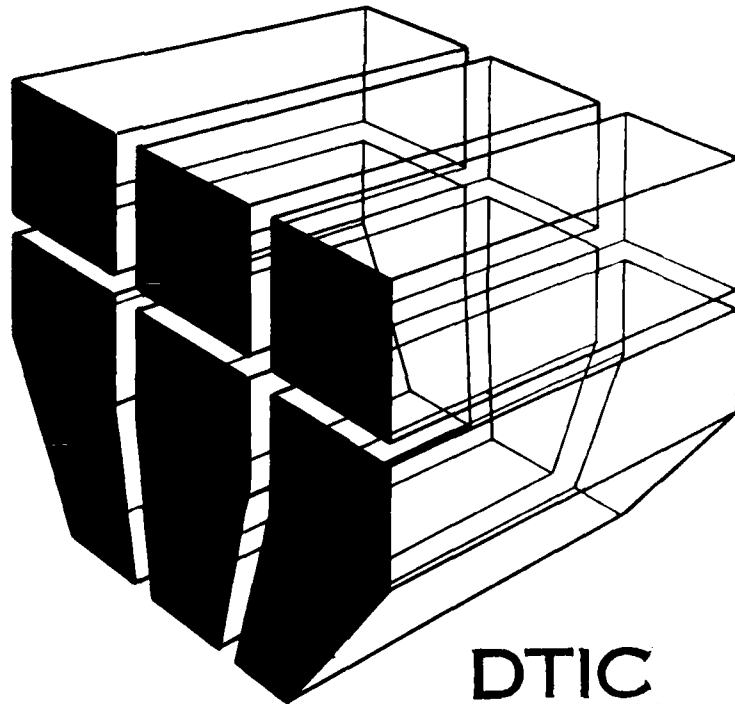
CEERL

Technical Report M-357
September 1984

Improved and New Roofing
for Military Construction

**FIELD TEST RESULTS OF EXPERIMENTAL EPDM
AND PUF ROOFING**

by
Myer J. Rosenfield



DTIC FILE COPY

DTIC
ELECTE
NOV 20 1984
B

Approved for public release; distribution unlimited.

84 11 14 011

REPRODUCED AT GOVERNMENT EXPENSE

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official indorsement or approval of the use of such commercial products. The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

**DESTROY THIS REPORT WHEN IT IS NO LONGER NEEDED
DO NOT RETURN IT TO THE ORIGINATOR**

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CERL-TR M-357	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Field Test Results of Experimental EPDM and PUF Roofing		5. TYPE OF REPORT & PERIOD COVERED FINAL
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Myer J. Rosenfield		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Construction Engr Research Laboratory P.O. Box 4005 Champaign, IL 61820-1305		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 4A762731AT41-A-044
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE September 1984
		13. NUMBER OF PAGES 73
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Copies are available from the National Technical Information Service Springfield, VA 22161		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) EPDM PUF ethylene propylene diene monomer polyurethane foam roofs		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report presents the results of 2 years of study of ethylene propylene diene monomer (EPDM) and sprayed-in-place polyurethane foam (PUF) roofs following their installation. Initial samples taken from the materials as delivered were tested to establish initial characteristics. Further samples were cut from the roofs every 6 months for 2 years to determine what changes were occurring from natural aging. Thermocouples and strain gages were also used to study response of the roof systems to changes in ambient conditions. (Continued)		

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

BLOCK 20. (Cont'd)

The EPDM showed an increase in mechanical properties during the first 6 to 12 months, probably due to completion of the curing process, followed by no significant change in properties for the rest of the test period. There was little consistency to the results for PUF during the same time of exposure. This could happen for several reasons: differences among PUF products used, application techniques, and inconsistent atmospheric conditions during application.

Test results indicated that both EPDM and PUF, when properly installed, will perform satisfactorily.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

FOREWORD

This work was performed by the Engineering and Materials (EM) Division of the U.S. Army Construction Engineering Research Laboratory (USA-CERL) for the Directorate of Engineering and Construction, Office of the Chief of Engineers (OCE), under Project 4A762731AT41, "Military Facilities Engineering Technology"; Task A, "Facilities Planning and Design"; Work Unit 044, "Improved and New Roofing for Military Construction." The OCE Technical Monitor was Mr. Joel Seifer, DAEN-ZCF-B.

Appreciation is expressed to the personnel at Forts Benning, Knox, and Lewis for taking samples from the test roofs and tape recordings of the weather and instrument data; to Mr. Bernard V. Jones and Mr. Vernon L. Kuehn of the U.S. Bureau of Reclamation for performing the mechanical and physical tests on the material samples; and to Prof. Donald E. Brotherson of the University of Illinois for reducing and analyzing the recorded data.

Dr. Robert Quattrone is Chief of USA-CERL-EM. COL Paul J. Theuer is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.



Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

CONTENTS

	Page
DD FORM 1473	1
FOREWORD	3
LIST OF TABLES AND FIGURES	5
1 INTRODUCTION	9
Background	
Objective	
Approach	
Mode of Technology Transfer	
2 DESCRIPTION OF TEST PROGRAM	9
Construction of Test Roofs	
Test Program	
3 PHYSICAL AND MECHANICAL PROPERTY CHANGES	11
Manufacture of EPDM Membrane Materials	
EPDM Property Changes	
Manufacture of Polyurethane	
Description of Coatings for PUF	
PUF Roofing Property Changes	
Built-Up Roofing	
4 STRAIN AND TEMPERATURE RESPONSES	15
Instrumentation	
Roof Surface Temperatures	
Strain Gage Readings	
5 SIGNIFICANCE OF DATA	17
6 RESULTS OF VISUAL OBSERVATIONS	18
First Annual Inspections	
Second Annual Inspections	
Third Annual Inspections	
7 CONCLUSIONS AND RECOMMENDATIONS	20
REFERENCES	20
METRIC CONVERSION FACTORS	20
TABLES	21
REMARKS AND OBSERVATIONS FOR TABLES 4 THROUGH 10	35
FIGURES	36
DISTRIBUTION	

TABLES

Number		Page
1	PUF Test Characteristics	21
2	EPDM Test Characteristics	22
3	BUR Test Characteristics	23
4	Initial Properties of EPDM Roofing Materials	24
5	Aged Properties of EPDM Membrane at Fort Benning	26
6	Aged Properties of EPDM Membrane at Fort Lewis	27
7	Initial Properties of PUF Roofing Materials	28
8	PUF — Initial and Aged Characteristics, at Fort Benning	30
9	PUF — Initial and Aged Characteristics, at Fort Knox	31
10	PUF — Initial and Aged Characteristics, at Fort Lewis	32
11	Initial Properties of BUR Materials	33
12	Roof Surface Temperatures	34

FIGURES

1	EPDM Roofs, Cross Sections	36
2	PUF Roofs, Cross Sections	36
3	BUR Roofs, Cross Sections	36
4	Building Selected for EPDM and BUR at Fort Benning	37
5	Building Selected for PUF Roofing at Fort Benning	38
6	Building Selected for PUF Roofing at Fort Knox	39
7	Building Selected for EPDM, BUR, and PUF at Fort Lewis	40
8	EPDM Manufacture	41
9	Typical Group of EPDM Sample Patches	42
10	Interlaminar Blisters in Foam at Fort Knox	42

FIGURES (Cont'd)

Number	Page
11 Fort Benning Control Fraction I	43
12 Fort Benning Control Fraction II	43
13 Fort Benning 18-Month Fraction I	44
14 Fort Benning 18-Month Fraction II	44
15 Fort Benning 24-Month Fraction I	45
16 Fort Benning 24-Month Fraction II	45
17 Fort Lewis Control Fraction I	46
18 Fort Lewis Control Fraction II	46
19 Fort Lewis 12-Month Fraction I	47
20 Fort Lewis 12-Month Fraction II	47
21 Fort Lewis 18-Month Fraction I	48
22 Fort Lewis 18-Month Fraction II	48
23 Weather Station at Fort Benning	49
24 Thermocouples Below Insulation—Building 2823, Fort Benning	50
25 Thermocouples and Strain Gages on Top of Membranes— Building 2823, Fort Benning	51
26 Data Recording Equipment Room Layout—Fort Benning	52
27 Weather Station at Fort Lewis	52
28 Thermocouples Below Insulation—Building 1450, Fort Lewis	53
29 Thermocouples and Strain Gages on Top of Membranes— Building 1450, Fort Lewis	54
30 EPDM Temperature vs. Solar Radiation—Fort Lewis	55
31 PUF Temperature vs. Solar Radiation—Fort Lewis	56
32 BUR Temperature vs. Solar Radiation—Fort Lewis	57
33 EPDM Temperature vs. Solar Radiation—Fort Benning	58
34 BUR Temperature vs. Solar Radiation—Fort Benning	59

FIGURES (Cont'd)

Number		Page
35	Deck Temperature Under EPDM vs. Solar Radiation—Fort Lewis	60
36	Deck Temperature Under PUF vs. Solar Radiation—Fort Lewis	61
37	Deck Temperature Under BUR vs. Solar Radiation—Fort Lewis	62
38	Deck Temperature Under EPDM vs. Solar Radiation—Fort Benning	63
39	Deck Temperature Under BUR vs. Solar Radiation—Fort Benning	64
40	Parameters vs. Time, High Temperature and High Sun— Fort Lewis, August 10–12, 1981	65
41	Parameters vs. Time, High Temperature and Low Sun— Fort Lewis, August 28–30, 1981	66
42	Parameters vs. Time, Low Temperature and High Sun— Fort Lewis, September 10–12, 1981	67
43	Parameters vs. Time, Low Temperature and Low Sun— Fort Lewis, November 28–30, 1981	68
44	Parameters vs. Time, High Temperature and Low Sun— Fort Benning, September 3–5, 1981	69
45	Parameters vs. Time, High Temperature and High Sun— Fort Benning, September 10–12, 1981	70
46	Parameters vs. Time, Low Temperature and High Sun— Fort Benning, January 9–11, 1982	71
47	Parameters vs. Time, Low Temperature and Low Sun— Fort Benning, January 12–14, 1982	72
48	Blister Over Nail Head at Fort Lewis	73

FIELD TEST RESULTS OF EXPERIMENTAL EPDM AND PUF ROOFING

1 INTRODUCTION

Background

Most Army facilities use conventional roofing systems, such as built-up roofing (BUR), that are sometimes expensive and complicated to construct. These conventional roofing systems are often comparatively short-lived, resulting in high life-cycle roofing costs which are difficult for already overburdened Army operation and maintenance budgets to absorb. Therefore, the Office of the Chief of Engineers has asked the U.S. Army Construction Engineering Research Laboratory (USA-CERL) to attempt to identify alternative, easy-to-install roofing systems that can improve the performance of Army roofing while reducing life-cycle costs. This involves (1) evaluating innovative roofing systems and materials to determine alternatives to BUR systems, (2) providing a means to improve Army roof performance and reduce life-cycle costs, (3) improving contractor quality control (CQC) of BUR construction, and (4) developing or improving guide specifications for selected alternative systems.

Previous work identified and evaluated alternative roofing systems that would be less susceptible to installation error or misapplication and would not be as sensitive to storage, handling, and weather considerations.¹ Three of these systems were selected for field evaluation by means of full-scale roof construction. These were the single-ply membranes of the ethylene-propylene-diene monomer (EPDM) and polyvinyl chloride (PVC) types, and the sprayed-in-place polyurethane foam (PUF) with a suitable elastomeric coating. EPDM and PUF roofs were constructed in 1980,²

and the PVC roofs were completed during summer 1983.³

Objective

The objective of this report is to document the results of a field test program to evaluate the EPDM and PUF systems.

Approach

The following procedures were used to carry out the objective of this study:

1. Roof systems for a 2-year field evaluation were selected based on earlier USA-CERL studies.⁴
2. A test plan was developed using standard test methods published by the American Society for Testing and Materials (ASTM) where available, and other tests developed by Government agencies where needed.
3. Test sites were selected.
4. Test guide specifications were developed.
5. Instrumentation systems were designed.
6. Construction of the test roofing systems was monitored.
7. Test data were collected for 2 years after completion of construction.
8. Each roof was inspected visually once a year.

Mode of Technology Transfer

Information generated by this study will impact on Corps of Engineers Guide Specification (CEGS) 07530, *Elastomeric Roofing (EPDM)*, and CEGS 07540, *Elastomeric Roofing, Fluid Applied*.

2 DESCRIPTION OF TEST PROGRAM

Construction of Test Roofs

Two EPDM roofs were constructed: one at Fort Benning, GA, and one at Fort Lewis, WA. Both are fully adhered, unballasted systems, with the membrane

¹E. Marvin, et al., *Evaluation of Alternative Reroofing Systems*, Interim Report M-263/ADA071578 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], 1979); Myer J. Rosenfield, *An Evaluation of Polyvinyl Chloride (PVC) Single-Ply Membrane Roofing Systems*, Technical Report M-284/ADA097931 (USA-CERL, 1981); Myer J. Rosenfield, *Evaluation of Sprayed Polyurethane Foam Roofing and Protective Coatings*, Technical Report M-297/ADA109696 (USA-CERL, 1981).

²M. J. Rosenfield and D. E. Brotherson, *Construction of Experimental Roofing*, Technical Report M-298/ADA109595 (USA-CERL, 1981).

³Myer J. Rosenfield, *Construction of Experimental Polyvinyl Chloride (PVC) Roofing*, Technical Report M-343 (USA-CERL, 1984).

⁴E. Marvin, et al., 1979.

attached to the surface; insulation is sufficient to give the roofing system an overall R-value of 20.

The system at Fort Benning consists of a fluted steel deck, 3 in. (76 mm) of composite board insulation mechanically fastened to the deck, and 60-mil (1.5-mm)-thick single-ply EPDM membrane. The system at Fort Lewis consists of a poured-in-place concrete roof deck, a one-ply vapor retarder of No. 43 asphalt-saturated and coated glass fiber base sheet in hot asphalt, 2½ in. (64 mm) of rigid inorganic board stock with asphalt-saturated organic felt facer sheets installed in hot asphalt, and a 60-mil (1.5-mm)-thick single-ply EPDM membrane. Figure 1 shows cross sections of those EPDM roofs.

Three PUF roofs were constructed: one each at Fort Benning, GA, Fort Knox, KY, and Fort Lewis, WA (Figure 2). The system at Fort Benning consists of a poured-in-place concrete roof deck, a two-ply vapor retarder of No. 15 asphalt-saturated organic felt, a minimum of 3½ in. (90 mm) of sprayed PUF, and a minimum of 20 mils (0.5 mm) of a single-component, moisture-cured silicone coating, applied in two coats with granules in the second coat.

The system at Fort Knox consists of a gypsum plant deck, one ply of asphalt-saturated base sheet nailed to this deck, a minimum 4 in. (102 mm) of sprayed PUF, and two coats of a single-component, moisture-cured silicone coating, with granules in the second coat. Although the minimum thickness was specified as 20 mils (0.5 mm), it was actually determined to be 12 mils (0.3 mm).

The system at Fort Lewis consists of a poured-in-place concrete roof deck, one ply of No. 43 asphalt-saturated and coated glass fiber base sheet in hot asphalt, a minimum 3 in. (76 mm) of sprayed PUF, and a coating consisting of a base coat of a two-component polyurethane elastomer and a top coat of chlorosulfonated polyethylene with granules in the top coat. The minimum thickness was specified as 20 mils (0.5 mm) but was actually determined to be 10 mils (0.25 mm).

In addition to the EPDM and PUF roofing systems, a conventional BUR was installed as a control at Forts Benning and Lewis (Figure 3). The system at Fort Benning consists of the same type of deck and insulation as the EPDM system, with a four-ply organic felt and asphalt BUR coated with aggregate specified as conforming to ASTM D 1863-77. The system at Fort Lewis consists of the same type of deck and vapor

retarder as the EPDM and PUF systems, but uses tapered insulation of polystyrene covered with a ½-in. (13-mm) layer of rigid fiberboard, with a four-ply BUR consisting of three plies of glass fiber felt in asphalt and a top ply of mineral-surfaced glass fiber cap sheet.

Figures 4 through 7 show the buildings selected, respectively, for EPDM and BUR roofing at Fort Benning; PUF roofing at Fort Benning; PUF roofing at Fort Knox; and EPDM, PUF, and BUR roofing at Fort Lewis. USA-CERL Technical Report M-298 describes construction of these systems.

Test Program

The test program was designed to determine how weathering would change the mechanical and physical characteristics of the three systems. Properties selected for study were those deemed essential to successful performance of the materials in a roof assembly. American Society for Testing and Materials (ASTM) standards were used as much as possible to determine these properties. Where no ASTM test method could be found, tests developed by the U.S. Bureau of Reclamation (USBR) or the U.S. Navy Civil Engineering Laboratory (NCEL) were used.

To establish a relationship between property changes and exposure to the weather, the test and control systems were instrumented to monitor and record the following:

1. Thermal conditions within the roof systems.
2. Weather conditions at the test site, including temperature, humidity, solar radiation, and wind speed and direction.
3. Strains that occurred within the EPDM roof system.

The initial set of tests was designed to establish the mechanical and physical characteristics of the materials at the time of application. Subsequent tests were scheduled at 6-month intervals over a 2-year period and once a year for 8 more years to establish a pattern of performance or to note changes in properties. A final test of field-exposed materials is proposed for 10 years after construction is completed. In addition to the laboratory tests, visual inspections are being made once a year to check for changes in appearance, loss of adhesion of EPDM or PUF coating, blistering, cracking, pinholing, loss of granules, or any evidence of mechanical damage from foot or equipment traffic.

unauthorized attachments or penetrations, or natural phenomena such as hail.

Tables 1 through 3 list the PUF, EPDM, and BUR characteristics, respectively, of interest to this study. As shown in Table 3, original plans were to measure strains in the BUR assembly. However, preliminary laboratory attempts at calibration indicated that such strains could not be measured due to softening of the asphalt resulting in plastic flow.

3 PHYSICAL AND MECHANICAL PROPERTY CHANGES

Manufacture of EPDM Membrane Materials

Understanding the test results, especially the original properties of the materials, is not possible without first reviewing the manufacturing process, particularly of the EPDM membrane. It is often assumed that EPDM is the same material, regardless of its source; however, this is not the case.

Figure 8 shows an abbreviated flow sheet for EPDM membrane manufacture. Ethylene and propylene occur in petroleum refinery off gases, or can be produced by cracking propane.⁵ The polymer chain produced from these two gases does not contain sufficient unsaturation for conventional vulcanization, so another ingredient must be added. Dienes such as butadiene, hexadiene, cyclopentadiene, dicyclopentadiene, etc., make this valuable property possible. The resin produced from reacting these materials is mixed with additives, chiefly carbon black. The resulting material is rolled into slabs which are then converted into the familiar rolls of roofing membrane on a calender. Many of the necessary operations, such as laminating, vulcanization, talc application, and trimming, have been omitted from Figure 8.

It is now apparent that the term "EPDM" does not necessarily describe a single product, but more properly applies to a family of products. Proportions of ethylene and propylene and the diene used may vary, depending on availability, price, and formula. Exact proportions are proprietary information, which is not released by the various manufacturers. Specific additives

may vary by time and by producer. Thus, even the products of one company may differ from one time to the next.

EPDM Property Changes

Initial EPDM Properties

Considering the above discussion, the differences between the initial values, shown in Table 4, can now be understood. The EPDM materials delivered to the two sites are the products of the same manufacturer. The test values shown are averaged from several tests on the materials delivered to each location: the range of values is also stated.

The mechanical properties of the delivered materials (tensile strength, elongation, and hardness) exceed the values that were specified, which are the minimums stated in the manufacturer's literature. These values indicate good-quality rubber sheet. The field seam strength appears to be very low, however. A minimum peel strength value of 5 lb/in. (0.876 N/mm) of width would be more appropriate. The shear strength of the seams at Fort Benning is 18 lb/in. (3.5 N/mm) of width, or only 20 percent of the sheet strength, while that of the seams at Fort Lewis is 28.7 lb/in. (5.02 N/mm) of width, or 29 percent of the sheet strength. According to the manufacturer, the shear strength of the seam should be at least 30 percent of the sheet strength. Observations of the seam area after separation indicated that the sheet was not completely cleaned of its talc coating before the seam cement was applied.

Of the physical properties, only the brittleness, ozone resistance, and water vapor permeability were specified. Water absorption and abrasion loss were determined so that the effect of aging on these properties could also be measured. The brittleness value was exceeded and the ozone resistance was met, but a difference was noted for the water vapor permeability, which was specified as 2.0 perm-mils ($2918 \text{ ng} \cdot \text{PA}^{-1} \cdot \text{S}^{-1} \cdot \text{m}^{-1}$). According to the manufacturer, this is neither a maximum nor a minimum, but is the actual value as determined in the laboratory. The measured value at Fort Benning of .06 perm ($3.4 \text{ ng} \cdot \text{PA}^{-1} \cdot \text{S}^{-1} \cdot \text{m}^{-2}$) calculates to 3.6 perm-mils ($5371 \text{ ng} \cdot \text{PA}^{-1} \cdot \text{S}^{-1} \cdot \text{m}^{-2}$) while the Fort Lewis value of 0.04 perm ($2.3 \text{ ng} \cdot \text{PA}^{-1} \cdot \text{S}^{-1} \cdot \text{m}^{-2}$) calculates to 2.4 perm-mils ($3581 \text{ ng} \cdot \text{PA}^{-1} \cdot \text{S}^{-1} \cdot \text{m}^{-1}$). Any value less than 1 perm (57.4 ng) is considered to be a vapor retarder, and the manufacturer describes this product as impermeable. The manufacturer's determination was conducted by Procedure BW of ASTM E 96, while the results of the USA-CERL study were obtained from Procedure B of

⁵R. Norris Shreve and J. A. Brink, Jr., *Chemical Process Industries*, 4th ed. (McGraw Hill Book Company, 1977), p 645.

the same test method, since the testing laboratory did not have the proper equipment for Procedure BW. Test method E 96 states that "agreement should not be expected between results obtained by different methods,"⁶ so even though the measured values are not the same, they are of the same order of magnitude and are close. What is significant is the change that occurs in the value with the lapse of time.

Changes in EPDM Properties With Time

Tables 5 and 6 outline the aged physical and mechanical properties of the EPDM membrane at Fort Benning and Fort Lewis, respectively. The changes in property values indicate a slight deterioration in many of the desirable characteristics of the material. Since the dimensional stability test indicates negligible shrinkage (Table 4), changes in tensile strength do not appear significant. However, the decrease in elongation could be serious, depending on the amount of relative movement between various components of the roofing system. Visual inspections to date have indicated no cracking or tearing of the membrane, but this will be one of the aging effects to be looked for during inspections over the next 8 years.

Tests by others⁷ indicate that the EPDM roof materials display reduced elongation properties, increased tensile strength, and increased hardness after accelerated aging. Results of the field test shown in Tables 5 and 6 indicate similar effects of natural aging. There was an initial increase in tensile properties after exposure of 6 months at Fort Benning, but the tests after 12, 18, and 24 months indicate a gradual return to lower properties. At Fort Lewis, a small increase was evident after exposure of 12 months, with a much larger increase after 18 months.

Decreases in elongation and abrasion loss indicate long-term hardening of the material. It has also been observed that repair of the cutouts for sample removal becomes more difficult over time. For the newly installed material, washing the seam area with heptane or white gasoline to remove the talc (according to the manufacturer's instructions) was sufficient for the contact adhesive to produce a good bond. It later became necessary to abrade the contacting surfaces of

the roof membrane and the patch, in addition to the washing, in order for the adhesive to bond to them both. This could result from the apparent hardening of the membrane, from oxidation of the membrane surface, or both. In any case, it indicates that special attention to technique is necessary if aged EPDM membranes must be repaired.

Water vapor transmission, slight as it was initially, has decreased with time. Since EPDM is not considered a "breathable" membrane, the change in this property is not in itself important. Its significance is only apparent when viewed in the context of changes to the other properties.

Equally significant is the slight rise in the glass transition temperature, which is the temperature range where heat is absorbed as the material undergoes a phase change. In the case of EPDM, the value is far below the temperatures normally expected in the continental United States.

The only property which behaved differently at Forts Benning and Lewis is the Shore A hardness. This showed an increase at Benning and a decrease at Lewis.

None of these property changes is expected to affect the long-term serviceability of the EPDM membranes, since the changes seem to level off in time. This is probably due to a short-term continuation of the curing process as a result of exposure to the elements.

Figure 9 shows a typical group of patches where samples were taken.

Manufacture of Polyurethane

Like EPDM rubber, manufacture of polyurethanes is not consistent. Polyurethanes are the reaction products of certain organic diisocyanates and polyglycols.⁸ The resulting compounds are either specialty rubbers of outstanding properties, possessing high abrasion resistance, which are useful at high temperatures and with high concentrations of solvents and oxygen or ozone, or they may be hard, glossy polymers. A major use for the rubber type is for producing flexible foam; the major use for the hard polymer type is for producing rigid foam.

The reaction of the two components may be extremely rapid. Evolving gas expands the mass, yielding foams which are either hard or soft, depending on the

⁶Standard Test Methods for Water Vapor Transmission of Materials, ASTM E 96-80 (American Society for Testing and Materials, October 31, 1980).

⁷Rene Dupuis, et al., *Temperature Induced Behavior of New and Aged Roof Membranes*, Proceedings, Second International Symposium on Roofs and Roofing, Brighton, England (September 1981).

⁸Shreve and Brink, p 643.

reactants and the conditions. Additional gas may be supplied to regulate the density of the resultant foam.

Rigid foams use aromatic di- or poly-isocyanates.⁹ Such compounds are toxic and are generally eye and respiratory irritants. The poly-isocyanates typically have lower vapor pressures and are less likely to cause vapor-induced irritation. These isocyanates, called "resins," are reacted with hydroxyl-terminated polyethers, known as "polyols." The number and types of these reactants are many and varied; the specific ones used depend on the manufacturer, the end product desired, availability, and price. Gases used for foam formation, called "blowing agents," are chlorinated fluorocarbons (CFC), the most common being trichlorofluoromethane (CCl_3F), commonly known as the refrigerant R-11. Experience in the industry has shown that foams with densities between 2.5 and 3.5 pcf, having minimum compressive strength of 40 psi, are necessary to withstand the abuse of foot traffic without crushing.

In addition to the reactants and blowing agent, small amounts of catalysts are used to control the rate of reaction. Surfactants are used to regulate cell size and cell wall rigidity, and fillers are used to extend the foam to lower its cost or alter a physical property. Additives, such as flame retardants, antioxidants, and pigments are used to impart other desired characteristics.

Description of Coatings for PUF

Corps of Engineers Guide Specification CECS 07540, *Elastomeric Roofing, Fluid Applied*, presently limits the elastomeric coating for sprayed PUF roofing to silicone materials.* Silicones are available in two forms: a two-component, catalyzed liquid which is mixed in the gun as it is sprayed, and a single-component, moisture-cured liquid which requires no mixing. These materials have demonstrated excellent retention of all necessary properties.

The urethane base coat/Hypalon** top coat system was selected to obtain a basis for evaluating a different

coating. Each system included an application of ceramic granules applied to the top coat while it was still fluid.

PUF Roofing Property Changes

Initial Foam and Coating Properties

The initial values of the PUF properties (Table 7) reflect the differences between the products of three manufacturers. Densities of the foams were within the specified range. Closed-cell content exceeded the 90 percent value normally expected for sprayed PUF within the specified density range.¹⁰ Compressive strengths of the foams at Forts Benning and Knox exceeded the specified value of 40 psi (27.6 N/cm^2), but the foam at Fort Lewis, with a minimum compressive strength of 35 psi (25.2 N/cm^2), cannot be considered as having met specifications. No foam met the specified tensile properties, but the high tensile strength at Fort Benning indicates better interlayer adhesion than at either Fort Knox or Fort Lewis. In general, the polyurethane foam at Fort Lewis was found to be slightly different in cell structure and material composition from the foams at Forts Benning and Knox. This difference is indicated by lower strength and closed-cell content as well as higher water vapor transmission and dimension change.

Dimensional stability values are reported by the manufacturers as the percent change in linear dimension in the direction of foam rise. The samples from the field were allowed to expand unrestrained. Linear dimensional stability values in the direction of rise were comparable to those claimed by the manufacturers. Overall, the initial properties exhibited by the three PUF materials fell within the normal ranges expected.

For the coatings, the only values specified were minimum thickness and maximum perm rating. The variation in thicknesses cannot be attributed only to foam surface texture, since the foam at Fort Lewis had a smoother surface than at either Fort Benning or Fort Knox, and the coating at Fort Benning met the specified minimum thickness. Application technique undoubtedly had much influence on the results. All coatings met the specified water vapor transmission (WVT) requirements.

Measured and advertised properties for the coatings could not be compared. Since coating thicknesses were

⁹W. C. Cullen and W. J. Rossiter, *Guidelines for Selection of and Use of Foam Polyurethane Roofing Systems*, Technical Note 778 (National Bureau of Standards, May 1973).

*At the time this report was prepared, CECS 07540 was being revised to permit the use of other coating materials.

**Hypalon is the registered trade name for chlorosulfonated polyethylene of the E. I. DuPont de Nemours and Co.

¹⁰*Properties of Rigid Urethane Foams*, Elastomer Chemicals Department (E. I. DuPont de Nemours and Company).

so varied for any given sample, determination of tensile properties would be meaningless. The manufacturers do not publish the brittle temperatures of their products, so the determination of this property was for initial characterization only, as was the glass transition temperature. It should be repeated that the glass transition temperature is not the same as the brittle temperature, but is a temperature range in which heat is absorbed as the material undergoes a phase change. This difference is readily apparent from an inspection of data in the various tables. In keeping with the purposes and financial constraints of the test program, it was felt that only physical properties of the coatings would be significant, so the tensile properties were not determined.

Changes in PUF Roofing Properties Over Time

Except for one time each, samples of PUF roofing from Forts Benning and Lewis were taken on schedule. No intermediate samples were received from Fort Knox, so no valid conclusions can be drawn from changes in property values at this location. Therefore, discussion of property changes is limited to Forts Benning and Lewis. It must be emphasized that PUF, as used in liquid-applied roofing, is manufactured at the location of use, under ambient atmospheric conditions, and not within the enclosed space of a factory under controlled conditions. Trends therefore become more important than singularities which may result from a change in any one of many localized conditions.

Thus, it can be deduced that density, compressive strength, and water absorption do not show any significant change at either Benning or Lewis. Tensile strength values, however, need to be interpreted in the light of actual application methods. At first, it appears that the tensile strength of the Fort Lewis foam is much less than the value advertised by the manufacturer. However, this is not necessarily the case. The manufacturer performed the test on a monolithic block of the foam, whereas the sample from the field was composed of several layers. Failure occurred at an interface between layers and actually indicated interlaminar adhesion qualities rather than strength of the foam itself. The foam at Fort Knox apparently showed excellent interlaminar adhesion, with higher tensile test values than those reported by the manufacturer. The manufacturer of the Fort Benning foam does not report tensile strength in its published literature. Table 8 shows that the interlaminar bond strength of the foam at Fort Benning is declining. This will be kept in mind during the annual visual inspection of the roof, in case any blistering is observed. Interlaminar blisters have already been observed at Fort Knox (Figure 10), possibly be-

cause moisture was present on the surface of one of the lifts of foam as the next lift was being sprayed. The origin of the moisture could have been a drop of perspiration from the worker using the spraygun. When combined with the linear dimension change perpendicular to rise, the moisture can form the type of blister shown in Figure 10.

Tables 8 through 10 show the changes in coating properties with time. Glass transition temperatures have remained essentially constant, as have water vapor transmission (WVT) properties. During the annual visual inspections, it was observed that the granules are becoming dislodged, with many bare areas of coating appearing.

Tables 8 through 10 also outline changes in foam and coating assembly properties. Impact and indentation values at Fort Benning have markedly improved over the 2-year time, but the value of coating adhesion to the foam has shown a serious decrease. The manufacturer has recognized that this coating material exhibits a decrease in adhesion over time. The formulation of the base coat has been changed to provide increased adhesion and longer time retention of this property. On the other hand, impact properties at Fort Lewis show a deterioration, while coating adhesion has remained essentially constant.

Continuing visual inspections each year will pay particular attention to possible infiltration of water under the coating, which would tend to saturate the foam and destroy the bond between foam and coating.

Built-Up Roofing

Initial properties of the built-up roofing (BUR) installed at Forts Benning and Lewis were determined for material characterization only. Table 11 gives the results of these tests; as shown, the specified properties were not completely met by the materials used.

The aggregate at Fort Benning was larger in particle size than the ASTM D 1863-77 size range allows. More material was retained on both the 1/2-in. (13-mm) sieve and the 3/8-in. (10-mm) sieve than the specification allows. However, this is not considered a serious problem.

The glass roofing felt used at Fort Lewis met all the applicable criteria of ASTM D 2178-76, exceeding them by about 100 percent. However, the organic felt used at Fort Benning, which was certified as meeting ASTM D 226-77, did not comply, except for the perforations. Breaking strengths and unit weight were less

than specified values, while volatile loss was 50 percent higher. These results are not reflected in the service life of the two roofs. The roof at Fort Lewis is heavily blistered, but does not leak. The roof at Fort Benning is still in excellent condition and does not yet require maintenance.

Gas chromatographic/mass spectral analyses were conducted on samples cut periodically from the roofs to determine what changes occurred in the asphalt as it aged. In addition to the initial controls, tests were conducted on 18- and 24-month samples from Fort Benning and 12- and 18-month samples from Fort Lewis. By comparing the aged samples with the controls, it is possible to detect differences. Computer-generated traces of the various analyses exhibit differences which indicate that chemical changes have occurred in the asphalt as it aged on the roofs. The asphalts that were analyzed came from or near the top of the samples, where the effect of sun and water was more intense. All samples except the initial controls exhibit traces of chemicals identified as dialkyl esters of phthalic acid, indicating that these products are formed in the asphalt as it ages. They are volatile compounds, and as they are produced and lost, the asphalt will become brittle.

For Fort Benning, traces of the initial control samples are shown in Figures 11 and 12, the 18-month samples in Figures 13 and 14, and the 24-month samples in Figures 15 and 16. For Fort Lewis, traces of the initial control samples are shown in Figures 17 and 18, the 12-month samples in Figures 19 and 20, and the 18-month samples in Figures 21 and 22. The designations "Fraction I" and "Fraction II" on the figures refer to test runs which separated aliphatic from aromatic compounds in each sample. Fraction I refers to aliphatic compounds and Fraction II to aromatic compounds.

Attempts were made to measure changes in mechanical and physical properties as the asphalt aged. Results were inconclusive, since the tests are not sensitive enough to determine minute changes. In all cases, the spread of results was less than the anticipated experimental error, so these attempts are not reported.

4 STRAIN AND TEMPERATURE RESPONSES

Instrumentation

A part of the overall test plan was to monitor thermal conditions within the roof system and the weather

conditions at the test site, including air temperature, wind direction and speed, and solar radiation. An attempt was also made to monitor strains occurring in the EPDM membrane. The instrumentation system provides a thermal profile through the roof systems by the use of thermocouples installed at the insulation-deck interface and on the membrane surface. Mercury strain gages were attached to the surface of the EPDM membrane.

Fort Benning

Instrumentation was installed only on Building 2823. Thermocouples were installed on the structural deck below the insulation on the roof areas covered by the EPDM system and the conventional BUR. Additional thermocouples were installed on top of both membranes, and strain gages were installed on the EPDM membrane only. The weather station was placed on the BUR portion as shown in Figure 23. All wiring was brought into a room located below the BUR part of the building. Figures 24 and 25 show the locations of thermocouples and strain gages, and Figure 26 shows the equipment layout in the data recording room.

Fort Lewis

Instrumentation was installed on all three sections of Building 1450. Thermocouples were installed on the structural decks and on the surfaces of the three membranes. Strain gages were installed on the EPDM membrane surface only. The weather station was placed on the PUF system as shown in Figure 27. All wiring was brought into a room located under the PUF part of the building, where equipment similar to that at Fort Benning was located. Figures 28 and 29 show the locations of thermocouples and strain gages at Fort Lewis.

In both locations, data for 2 weeks were recorded on a cassette tape. This tape was mailed to USA-CERL, where the recordings were transferred to a master file. The cassettes were then returned for recording of more data.

Roof Surface Temperatures

Roof surface temperatures affect the performance of the roof system and the thermal load on the building. The data collected at Forts Benning and Lewis were subjected to statistical analysis using the Statistical Package for the Social Sciences (SPSS). Data were selected from April 1981, August 1981, October 1981, and January 1982 to represent four different periods during an exposure year.

The data indicate a strong relationship between the roof surface temperature and solar incidence, and a less significant relationship between roof surface temperatures and air temperatures. The black surface of the EPDM membrane experiences much higher temperatures than either the gravel-surfaced BUR or the white-coated PUF. The difference is statistically significant at solar incidence levels above 0.375 Langley. There appears to be almost no difference between the surface temperatures of the gravelled BUR and the PUF roofs. When roof surface temperatures were compared to air temperatures, it was observed that at air temperatures below 50°F (10°C), the EPDM was cooler than the other two roofs; at temperatures above 75°F (24°C), the EPDM was significantly warmer than the other two roofs.

The data for the instrumented roof systems for the four collection periods were divided into three levels of air temperature: low, medium, and high. They were then analyzed using scattergram and regression line techniques. Figures 30 through 34 show the relationships between roof surface temperatures and solar exposure for the three levels of air temperature and the five instrumented roofs at Forts Lewis and Benning. The roof temperatures represent an average of all the temperature points on the roof surface. When the diagrams were created, the options available were to use each thermocouple point plotted against the other parameters, or to combine all the points into one plot. Because of the variations of construction and activities within the buildings, it was not possible to select one thermocouple point as representative or typical of the whole roof. An examination of the data indicated that certain roof points were consistently warmer or cooler than other points on the same roof. Since there was no evidence that any one point was incorrect, all points were included. A 90 percent confidence interval constructed from the data for each of the roofs confirmed the decision to take the average of all the thermocouple points.

Table 12 lists minimum, maximum, and mean roof temperatures for selected days at Forts Benning and Lewis. The confidence interval depends on the average, the deviation, and the number of thermocouples involved. It is possible to have a large spread between minimum and maximum temperatures with a relatively small spread in the confidence interval because of the distribution around the mean and the total number of data points. For Figures 30 through 34, an equation for each of the regression lines is shown, as well as the standard error of estimate and the " R^2 ", a measure of

the strength of the linear relationship between the two variables.

Figures 35 through 39 are similar data plots, except that they relate the solar radiation to temperatures at the interface between the insulating material and the structural deck. There is an indication of some effect from solar radiation and air temperature, but the interface temperatures are probably more affected by inside than by outside temperatures. Data from the PUF roof at Fort Lewis substantiate this conclusion. Temperatures at the deck rose only 10°F (5.5°C) for a 40°F (22°C) rise in air temperature at one instance; temperatures never went below 60°F (16°C), even when outdoor temperature dropped to as low as 20°F (-7°C).

Strain Gage Readings

The successful application of strain gages to an elastomeric material such as EPDM or to a viscoelastic material such as BUR has not been reported for long-term studies. Unpublished investigations show some success for short-term tests on EPDM roofs and on elastomeric-coated fabrics. The strains in elastomeric materials can be expected to be much larger than those measured by conventional strain gages.

A number of different types of electrical strain gages were investigated during the initial stages of this study. Most were eliminated for reasons such as long-term stability, sensitivity to temperature changes, weatherability, problems of attachment, and other mechanical reasons. One series of tests was made on foil strain gages attached to omega-shaped strips of brass shim stock fastened to the membrane. This was not successful during field tests.

The final installation used mercury capillary gages attached directly to the membrane. The locations are shown in Figures 13 and 17. The gages indicate the change in strain as a change in electrical resistance. They were developed by the Southwest Research Institute (San Antonio, TX) to measure strain on the bow seals of surface effects ships (SES) and adapted for use on this project.

A plot of percent strain versus time for four of the gages at Fort Lewis shows twice daily peaks in the percent strain. Peaking began at about 0800 hours on two days and at about 1000 hours on the other five. The drop in percent strain occurred at about the same time each day. A second peak occurred again about 1900 hours, with completion of the cycle at about

2300 hours to midnight. This phenomenon was not evident at Fort Benning.

Figures 40 through 47 are each a composite of roof temperature, air temperature, solar incidence, and percent strain plotted against a three-day interval. The three-day periods, which were selected by using United States climatological data for the area, represent periods of high solar gain with high and low air temperatures, and low solar gain with high and low air temperatures. Since all four strain gages responded almost identically, only one gage is shown on the plots.

The plots clearly show the strong relationship between solar incidence and strain gage response. The plots with low solar incidence show virtually no change in percent strain, while those with high solar incidence show an almost immediate response to solar incidence. The double peak condition at Fort Lewis is very obvious in Figures 40 and 42.

Figures 40 through 47 show the time lag between rising-air and roof-surface temperatures. On days with little or no solar incidence and overcast skies, roof-surface temperatures followed air temperatures. In contrast, on clear nights the roof-surface temperatures were lower than the air temperatures. This is not unexpected and repeats data previously published by the National Bureau of Standards.¹¹

5 SIGNIFICANCE OF DATA

When evaluating any building material exposed to the natural environment for a long time, it is important to keep records of exposure period conditions. Lack of such a record greatly reduces the evaluation's significance. The instrumentation described in this report was designed to provide this record.

Just as important as the data is that the method of recording the data require only a minimum of attention and manpower. The analysis presented in this report indicates that the temperature-recording system has been successful and that relationships between ambient air, solar incidence, and roof temperatures have been established. The analysis shows extremes of temperature and daily cyclic changes.

¹¹William Cullen, *Solar Heating, Radiative Cooling, and Thermal Movement*, NBS Technical Note 231 (National Bureau of Standards, December 1963).

The significance of the strain gage data is not clear. The EPDM material exhibited strains of about 4 to 4.5 percent, which is well below the maximum allowable strain for this type of material. The data are useful for seeing the movement that occurs during daily cycling. However, the installations have not been reliable over long time spans and may only be useful during early stages of the test. It has also not been possible to explain the "double peak" that occurs in the data for gages installed at Fort Lewis. Discussions with various technical personnel have not produced an acceptable explanation. A laboratory test is needed to simulate the temperature and solar incidence on the roof so that a mercury gage attached to EPDM can be monitored. Such a test may indicate why this response of the field gages occurred.

The collection and analysis of roof temperatures and weather conditions is part of an overall study to evaluate alternative roofing systems. How these roof systems will age (i.e., what changes will occur in their physical characteristics over time) is of great concern to this program. Tests performed by others¹² indicate that the EPDM roof materials display reduced elongation properties, increased tensile strength, and increased hardness after accelerated aging. Preliminary test results of the physical characteristics of the test EPDM roofs at Forts Lewis and Benning agree with the elongation and hardness changes, but may disagree with tensile strength changes. There was an initial increase in tensile strength properties after a 6-month exposure at Fort Benning, but the last three tests after 12, 18, and 24 months of exposure indicate a gradual return to lower tensile strengths. At Fort Lewis, a small increase was evident after a 12-month exposure. Current plans are to continue removing samples for testing at 1-year intervals to monitor physical changes in the material.

From the weather data collected at Forts Benning and Lewis, it is evident that the solar intensity at Fort Lewis rarely exceeds 0.625 Langley, while at Fort Benning, it is often 1.0 Langley or higher. It is possible that the intensity of the solar radiation, as well as the total solar incidence, may have a very marked effect on the aging process.

Accelerated weathering techniques must intensify the exposure conditions to affect the aging process. As with other building materials, such as paints, sealants, and traditional roofing materials, the acceleration

¹²Rene Dupuis, et al., 1981.

process may not provide a true picture of the aging process on the EPDM roof materials.

Continued monitoring of the EPDM roof systems will provide an excellent means of comparing accelerated and long-term testing. It will also help determine the usefulness of accelerated tests as a means of evaluating roof systems.

The physical properties of PUF have also been tested on samples removed from roofs at Forts Lewis, Benning, and Knox. Tests of density, compressive strength, interlaminar bond strength, and water absorption show both negative and positive changes. The only possibly significant change appears to be at Fort Benning, where interlaminar bond strength has declined from an average of 78 lb/sq in. (538 kN/m²) (60 to 89 range) (414 to 614 range) to an average 36 lb/sq in. (248 kN/m²) (0 to 75 range) (0 to 517 range). Coating vapor transmission rates have increased, mainly due to granule loss resulting in pinholes in the coating. Coating glass transition appears to be stable, but coating adhesion appears to be declining. Average values of 160 to 198 lb/sq in. (1103 to 1365 kN/m²) have declined to average values of 115 to 156 lb/sq in. (793 to 1076 kN/m²) over the 24-month test period.

The most severe declines in coating adhesion and interlaminar bond strength have occurred at Fort Benning. Degradation of the PUF roof is probably not related to temperature or exposure, but most likely is a direct result of the application problems encountered by the contractor.¹³

The foam assembly is also being tested for indentation strength and impact strength. Indentation strength has shown increased values at all three sites. Impact strength has increased at Fort Benning, while declining at Forts Knox and Lewis.

Continued monitoring of the PUF systems will provide data to help determine if further degradation is related to exposure factors or to application problems.

6 RESULTS OF VISUAL OBSERVATIONS

Each roof has been inspected annually as part of the evaluation process. At each inspection, the roof is care-

fully checked for visible signs of deterioration. Special attention is paid to the patches where samples for testing have been removed, as well as to flashings and indications of maintenance or repair.

First Annual Inspections

The first annual inspections (July 1981) indicated only minor problems. Granules were not firmly adhered to the coatings on the PUF roofs and were washing down the drains and collecting in depressions in the foam. At Fort Knox, the vent from a heating boiler was causing a large rust stain to form on the roof surface, but this was not causing any apparent deterioration.

Minor problems were already becoming evident on the EPDM roofs. At Fort Benning, there were a few minor blisters, evidently caused by wrinkles in the sheet at the time of installation. At Fort Lewis, some blistering was occurring above the nail heads where the membrane had been fastened to the wood nailers. At both locations, it was observed that patches over the sample cuts were not adhering properly to the membrane. Satisfactory repairs were achieved by abrading the contacting surfaces with wire brushes and coarse sandpaper, followed by renewed application of fresh contact cement.

The BUR at Fort Benning looked as if it had just been installed. Some slight blistering was evident in the BUR at Fort Lewis. Field personnel stated that blistering of BURs with mineral-coated cap sheets was very common at Fort Lewis, probably because of the combination of high humidity and mild temperatures which always exists there. The only 6-month samples taken were of the BUR and EPDM roofs at Fort Benning.

Second Annual Inspections

The second annual inspections (June 1982) indicated some need for maintenance. The PUF roof at Fort Benning was in excellent condition, but some blisters were beginning to form in the PUF roof at Fort Knox. Figure 10 is typical of this blistering. At both Forts Benning and Knox the foam samples were smaller than had been requested, so ideal data were not available. Sampling technique was discussed so that further samples would be the proper size. At Fort Knox, the second set of sample cuts had been patched with roofing felt and asphalt cement, as if the roof were a BUR. Proper repair techniques were discussed. Even though more than 2 years had elapsed since completion of construction, only the 24-month samples had ever been sent to the laboratory for analysis. The

¹³M. J. Rosenfield and D. E. Brotherson, 1981.

6- and 12-month samples had never been taken, and the 18-month samples had been lost.

The PUF roof at Fort Lewis was in excellent condition, except for flashing at a vent from a heating boiler. Design of this flashing had not allowed for expansion and contraction of the pipe, so the foam had broken. Proper flashing techniques were discussed. The coating over one of the patched areas where a sample had been removed was partially detached from the foamed repair. This could be repaired easily by abrading the foam surface and recoating the area.

The EPDM roofs at both Forts Benning and Lewis were generally in very good condition. One patch at Benning was no longer adhered to the membrane and needed repair. Two problems were evident at Fort Lewis. One was the presence of considerable ash from one of the Mount Saint Helens eruptions, which had occurred a year before the inspection. The other was the continued existence of small blisters above the nail heads. Figure 48 shows a typical blister. The membrane manufacturer was contacted about this problem. It had apparently occurred elsewhere, and repair methods were recommended.

The BUR at Fort Benning was still in excellent condition. However, the one at Fort Lewis was severely blistered and would soon need extensive repair or replacement.

It was noted that drains at Fort Lewis were constantly being plugged by debris blowing onto the roofs from the surrounding pine trees, causing water to remain ponded on the roofs for an excessive time after the rain had stopped. It was pointed out that these drains should be kept clear to remove the water.

Third Annual Inspections

The third annual inspections (June 1983) demonstrated the value of prompt and proper maintenance procedures. The PUF roof at Fort Benning was still in excellent condition, except for some scratches through the coating of one patch. All previously discovered deficiencies in the PUF roof at Fort Knox had been repaired recently, and the roof was in excellent condition. The vent from the boiler had been piped to discharge directly into a nearby gutter; all previous stains had been scrubbed off and the area given a fresh application of coating and granules.

However, at Fort Lewis, a serious problem had developed in the PUF roof since the previous inspection.

Twenty samples had by now been taken from the roof for inspection, and all had cracks through the coating around part or all of each perimeter. Eight had become so wet that water spurted out when they were stepped on. This is not to be construed as a defect in the PUF roofing system. On the contrary, the roof itself was still in sound condition. The defect occurred because of improper procedures for repairing the holes where samples were removed. Once these areas are removed and properly repaired, the roof will be in excellent condition. The only other deficiency noted was that wind had scoured the surface so that many bare streaks were now visible in the coating, showing where granules had been removed.

The EPDM roof at Fort Benning was still in generally very good condition. One patch had been sealed with the wrong type of sealant, which had deteriorated rapidly and was peeling away. A thorough cleaning and use of proper sealant will provide adequate repair. However, at Fort Lewis, a serious problem was now evident. The membrane had become detached from the underlying insulation around one of the drains. The watertight integrity of the membrane did not seem to be affected, however, and the insulation did not feel as if it were wet. The small blisters above the nail heads, noted during the previous year, had been repaired, but new ones had formed at the same locations. No surface cracks or crazing had appeared in either of the EPDM roofs.

The BUR at Fort Benning was still in excellent condition. Recent rains had caused some shallow ponding, but there was neither evidence nor history of roof leaks. Because of the high solar incidence and ambient temperatures, as well as the shallow depth of the ponds, the water tended to evaporate rapidly, usually lasting no longer than 2 to 3 days. Blistering in the BUR at Fort Lewis was even more pronounced than in the previous year, but only one leak had developed, and this had been repaired. Some blisters had opened, and these had been patched by spreading roofing cement over the surface. Discussion with Fort Lewis personnel indicated that the asphalt surface inside the blisters was shiny, indicating poor adhesion of the cap sheet to the BUR surface. However, it must be noted that the cap sheet was applied to the BUR surface after the three plies had been completely shingled in and allowed to cool; this undoubtedly led to a poor bond between the BUR and the cap sheet. Blistering of BURs with mineral-coated cap sheets is very common at Fort Lewis.

7 CONCLUSIONS AND RECOMMENDATIONS

EPDM single-ply membrane roofing, when properly applied and maintained, is a good material for use on Army and other Government buildings, having demonstrated the capability to retain its properties for a long period of time. Seaming techniques require close attention to ensure that the sheet is completely cleaned of talc or other coating before seam cement is applied. Repairs and corrections are relatively easy to perform when compared to the standard BUR.

When provided with adequate coating, PUF provides a lightweight roof which can be easily maintained to yield a long service life. Care must be taken during design to allow for situations where expansion and contraction of items penetrating the roof may tend to fracture the foam. Repairs to surface defects are simple to accomplish, but care must be taken when foam is removed and replaced so that leaks do not develop.

Conventional BUR can provide a serviceable roof, but the surfacing used can affect the durability of the final product; this may be due partly to the application of the cap sheet as a separate layer after the shingled felt has been applied.

Both EPDM and PUF can provide good-quality roofs with long life expectancy, and should be given widespread acceptance and use in military construction. Both systems are already approved for Army use.

Monitoring of the changes to physical and mechanical properties of the materials should continue to obtain complete data on the effect of aging under service conditions.

REFERENCES

- Cullen, William, *Solar Heating, Radiative Cooling, and Thermal Movement*, NBS Technical Note 231 (National Bureau of Standards, December 1963).
- Cullen, W. C., and W. J. Rossiter, *Guidelines for Selection of and Use of Foam Polyurethane Roofing Systems*, Technical Note 778 (National Bureau of Standards, May 1973).

Dupuis, Rene, et al., *Temperature Induced Behavior of New and Aged Roof Membranes*, Proceedings, Second International Symposium on Roofs and Roofing, Brighton, England (September 1981).

Marvin, E., et al., *Evaluation of Alternative Reroofing Systems*, Interim Report M-263/ADA071578 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], 1979).

Properties of Rigid Urethane Foams, Elastomer Chemicals Department (E. I. DuPont de Nemours and Company).

Rosenfield, Myer J., *An Evaluation of Polyvinyl Chloride (PVC) Single-Ply Membrane Roofing Systems*, Technical Report M-284/ADA097931 (USA-CERL, 1981).

Rosenfield, Myer J., *Evaluation of Sprayed Polyurethane Foam Roofing and Protective Coatings*, Technical Report M-297/ADA109696 (USA-CERL, 1981).

Rosenfield, M. J., and D. E. Brotherson, *Construction of Experimental Roofing*, Technical Report M-298/ADA109595 (USA-CERL, 1981).

Rosenfield, Myer J., *Construction of Experimental Polyvinyl Chloride (PVC) Roofing*, Technical Report M-343 (USA-CERL, 1984).

Shreve, R. Norris, and J. A. Brink, Jr., *Chemical Process Industries*, 4th ed. (McGraw-Hill Book Company, 1977).

Standard Test Methods for Water Vapor Transmission of Materials, ASTM E 96-80 (American Society for Testing and Materials, October 31, 1980).

METRIC CONVERSION FACTORS

$$1 \text{ lb/sq in.} = 703.070 \text{ Kg/m}^2 \text{ (mass)}$$

$$= 6.895 \text{ KN/m}^2 \text{ (force)}$$

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) \frac{5}{9}$$

$$1 \text{ perm-mil} = 1.459 \times 10^{-3} \text{ ng} \cdot \text{PA}^{-1} \cdot \text{S}^{-1} \cdot \text{m}^{-1}$$

$$1 \text{ lb/cu ft} = 16.0185 \text{ Kg/m}^3$$

Table 1
PUF Test Characteristics

Tests at Beginning of Exposure Program		Remarks
Property	Test Method	"Property" refers to physical properties of interest.
Foam		
Water Vapor Transmission	ASTM C 355	The amount of movement or dimensional change must not exceed the coating capacity.
Dimensional Stability	ASTM D 2126	
Closed Cell Content	ASTM D 2856	
Coating		
Thickness	USBR Test	These tests will establish "baseline" for coating for comparison with later tests taken from field-exposed samples.
Brittle Temperature	ASTM D 2137	
Tests at Beginning and Intermittently During Program		
Foam		
Foam Density	ASTM D 1622	The material must not deteriorate or lose density. Urethane foams are sensitive to moisture. Moisture may enter from below (condensation) or above (leakage).
Water Absorption	ASTM D 2842	
Tensile Strength	USBR Test	
Compressive Strength	ASTM D 1621	
Coating		
Water Vapor Transmission	ASTM E 96	
Glass Transition	ASTM D 3418	
Foam With Applied Coating		
Indentation Hardness	USBR Test	The foam and coating must be capable of resisting foot traffic and other mechanical abuses, including continued resistance to hail and falling objects.
Adhesion	NCEL Test	
Impact Resistance (with applied coating)	USBR Test	
Field Monitoring		
Visual Inspection		Check for adhesion loss, blistering, cracking, flaking, peeling, pinholing, hail damage, and severe cracking or erosion.
Weather Data		
Temperature		
Humidity		
Solar Radiation		
Wind Speed and Direction		
Temperature Measurements		
Thermocouples at interface of foam and supporting deck; on surface of coating.		

Table 2
EPDM Test Characteristics

Tests at Beginning of Exposure Program		
Property	Test Method	Remarks
Heat Aging	ASTM D 573	"Property" refers to physical properties of interest. This group of tests is used to provide a means of predicting weather performance. They will be used for comparison at the end of the 2-year period to see how well they predicted the actual condition of the membrane materials.
Accelerated Aging	ASTM D 2565	
Brittleness	ASTM D 2137	
Dimensional Stability	ASTM D 1204	
Tests at Beginning and Intermittently During Program		
Abrasion Loss	ASTM D 3389	These are tests to establish the basic physical characteristics typical of roof membranes. Any changes in these characteristics during service could signal aging, deterioration, and reduction of lifetime expectancy. Abrasion resistance is necessary if the roof will experience regular foot traffic; seam strength is essential in one-ply systems; changes in hardness indicate a loss of plasticizer and resistance to mechanical damage; absorption and permeability are necessary characteristics if the membrane is used over existing roofing systems with possible moisture entrapment; D 1876 and D 412 tests should be run at 70°F.
Seam Strength	ASTM D 1876 and D 882, Method A	
Tensile Strength	ASTM D 412	
Ultimate Elongation	ASTM D 412	
Hardness	ASTM D 2240	
Water Resistance		
Absorption	ASTM D 570	
Permeability	ASTM E 96, Proc. B	
Ozone Resistance	ASTM D 1149	
Glass Transition	ASTM D 3418	
Field Tests and Monitoring		
Weather Data		These measurements are needed to correlate with strain and temperature measurements.
Temperature		
Humidity		
Solar Radiation		
Wind Speed and Direction		
Strain Measurements		Previous studies indicate that these locations will give good data on movement within the membrane.
Some points on center line of test area with strain gages at 90 degrees to measure longitudinal and transverse strains. At some corners, penetrations, and at center of perimeter.		
Temperature Measurements		The thermocouple stack is a standard method of measuring temperatures in a building component. Thermocouples at strain gage locations are needed to correct strain gage output.
Thermocouples at interface of insulation and structural deck and at surface of membrane at strain gage locations.		
Periodic Field Observations		This type of inspection with photographs will provide a record of physical changes and/or appearance.
Visual Inspection		
Nondestructive Moisture Measurement		
		Moisture survey techniques (infra-red, nuclear, capacitance, and cores as needed) will be used to determine any changes in moisture content of the insulation.

Table 3
BUR Test Characteristics

Tests at Beginning of Exposure Program		
Property	Test Method	Remarks
Asphalt	ASTM D 312	These tests will establish that the materials used to construct the membrane meet minimum ASTM standards.
Surfacing	ASTM D 1863	
Felts	ASTM D 226, D 2178	
BUR Assembly	ASTM D 3617	This test taken during the assembly operation will establish the quality and quantity of the membrane materials.
 Tests at Beginning and Intermittently During Program		
Glass Transition	ASTM D 3418	Glass transition tests will be run as required.
Mass Spectrograph	ASTM E 137, E 304	This test will detect chemical changes with time as the asphalt weathers and ages.
 Field Tests and Monitoring		
Weather Data		
Temperature		
Humidity		
Solar Radiation		
Wind Speed		
 Strain Measurements		
Selected points at expected maximum and minimum strain.		This will reveal membrane movements.
 Temperature Measurement		
Thermocouple "stacks" at one or two locations and single thermocouples at strain gage locations.		These are needed to correct strain gage outputs and to conduct research on the thermal performance of the roof.

Table 4
Initial Properties of EPDM Roofing Materials

Property⁹	Specified Value	Test Method	Fort Benning	Fort Lewis
Tensile strength, lb/sq in.	1400	ASTM D 412	Average Range 1585 1445 to 1705	1705 1640 to 1845
		Transverse	Average Range 1525 1405 to 1650	1645 1135 to 1820
Elongation, percent	300**	ASTM D 412	Average Range 540 475 to 640	505 480 to 540
		Transverse	Average Range 580 530 to 640	515 480 to 580
Hardness, Shore "A"	50 to 70**	ASTM D 2240	Average Range 58 56 to 60	57 56 to 58
Ozone resistance	No cracks	ASTM D 1149	No cracks	No cracks
Water absorption, weight %		ASTM D 570	Average Range +0.5 0.26 to 0.72	+0.4 0.34 to 0.48
Vapor transmission, perm-mils	2.0***	ASTM E 96 Procedure B	Average Range 3.6 2.4 to 5.3	1.98 1.86 to 2.04
Glass temperature, °F	--50 max	ASTM D 3418	Average Range -60 -62 to -58	-65 -66 to -65
Abrasion loss, grams/1000 rev.		ASTM D 3389	Average Range 0.19 0.15 to 0.22	0.19 0.17 to 0.21

⁹Numbers refer to Remarks and Observations, p 35.

**Manufacturer's published value.

***Manufacturer's published value by Procedure BW.

Table 4 (Cont'd)

Property ^{2*}	Specified Value	Test Method	Fort Benning	Fort Lewis
Seam strength, lb/in. width		Peel	Average Range	2.5 1.6 to 4.3
		Shear	Average Range	28.7 22.8 to 34.0
Low temperature brittleness (°F)	-75**	ASTM D 2137	Average Range	-66 -65.0 to -66.4
Dimensional stability 24 hours at 100°F % change		Longitudinal	Average Range	0.0 -0.1 to 0.0
		Transverse	Average Range	-0.3 -0.5 to -0.1
Heat aging, longitudinal direction		ASTM D 1204	Average Range	100 97 to 103
Percent of original physical properties		Elongation	Average Range	70 65 to 80
		100% modulus	Average Range	136 128 to 143
Xenon arc exposure ^{2*}		Period exposed	ASTM D 2566	3-13-81/4-28-82 Operating hours 4024
Outdoor exposure ^{2*}		Period exposed Surface change Months	USBR	8-80 to 4-83 Surface graying—no significant change 32

*Numbers refer to Remarks and Observations, p 35.

**Manufacturer's published value.

Table 5
Aged Properties of EPDM Membrane at Fort Benning

Property ⁹ *	Test Method	Age-Months					
		0	6	12	18	24	30
Tensile strength, lb/sq in.	Longitudinal	Average	1585	1660	1650	1630	1627
	Transverse	Range	1445 to 1705	1610 to 1790	1580 to 1680	1590 to 1655	1516 to 1654
Elongation, percent	Longitudinal	Average	1525	1620	1610	1555	1585
	Transverse	Range	1405 to 1650	1565 to 1655	1505 to 1725	1524 to 1575	1491 to 1648
Hardness, Shore "A"	Longitudinal	Average	540	470	494	421	381
	Transverse	Range	475 to 640	440 to 505	470 to 510	410 to 431	335 to 420
Ozone resistance	Longitudinal	Average	580	500	425	435	402
	Transverse	Range	530 to 640	455 to 530	350 to 480	388 to 465	380 to 425
Water absorption, weight %	Longitudinal	Average	58	61	61	62	62
	Transverse	Range	56 to 60	60 to 62	60 to 62	61 to 62	61 to 62
Vapor transmission, perm-inils	Longitudinal	Average	No cracks	No cracks	No cracks	No cracks	No cracks
	Transverse	Range	No cracks	No cracks	No cracks	No cracks	No cracks
Glass temperature, °F	Longitudinal	Average	+0.5	+0.6	+0.7	+0.9	+0.9
	Transverse	Range	0.26 to 0.72	0.38 to 0.77	0.58 to 0.76	0.80 to 0.98	0.76 to 0.92
Abrasion loss, grams/1000 rev.	Longitudinal	Average	3.6	1.8	1.2	1.6	1.8
	Transverse	Range	2.4 to 5.3	1.7 to 1.8	1.2 to 1.2	1.4 to 1.8	1.7 to 1.9
Seam strength, lb/in. width	Longitudinal	Average	-60	-60	-60	-58	-54
	Transverse	Range	-62 to -58	-62 to -58	-62 to -58	-62 to -56	-54 to -53
Peel	Longitudinal	Average	0.19	0.16	0.13	0.08	0.09
	Transverse	Range	0.15 to 0.22	0.13 to 0.18	0.11 to 0.15	0.07 to 0.09	0.08 to 0.11
Shear	Longitudinal	Average	0.8	No sample	No sample	No sample	No sample
	Transverse	Range	0.4 to 2.0	No sample	No sample	No sample	No sample
26	Longitudinal	Average	18.0	No sample	No sample	No sample	No sample
	Transverse	Range	14.9 to 19.7	No sample	No sample	No sample	No sample

*Numbers refer to Remarks and Observations, p 35.

Table 6
Aged Properties of EPDM Membrane at Fort Lewis

Property ^{9*}	Test Method	Age-Months			
		0	12	18	24
Tensile strength, lb/sq in.	Longitudinal	Average Range	1705 1518 to 1879	1810 1793 to 1858	1761 1713 to 1810
	Transverse	Average Range	1645 1135 to 1820	1681 1563 to 1765	1721 1693 to 1773
Elongation, percent	Longitudinal	Average Range	505 480 to 540	495 424 to 569	449 385 to 473
	Transverse	Average Range	515 480 to 580	508 449 to 580	459 430 to 485
Hardness, Shore "A"	ASTM D 2240	Average Range	57 56 to 58	57 55 to 60	59 57 to 61
Ozone resistance	ASTM D 1149	No cracks	No cracks	No cracks	No cracks
Water absorption, weight %	ASTM D 570	Average Range	+0.4 0.34 to 0.48	+0.3 0.29 to 0.35	+0.7 0.67 to 0.81
Vapor transmission, perm-mils	ASTM E 96 Procedure B	Average Range	2.0 1.9 to 2.0	2.4 1.8 to 2.6	2.0 1.6 to 2.4
Glass temperature, °F	ASTM D 3418	Average Range	-65 -66 to -65	-58 -59 to -57	-59 -60 to -58
Abrasion loss, grams/1000 rev.	ASTM D 3389	Average Range	0.19 0.17 to 0.21	0.14 0.13 to 0.17	0.11 0.10 to 0.13
Seam strength, lb/in. width	Peel	Average Range	2.5 1.6 to 4.3	2.7 1.8 to 3.8	1.9 1.5 to 2.6
	Shear	Average Range	28.7 22.8 to 34.0	26.0 23.2 to 29.0	24.2 21.8 to 28.0

*Numbers refer to Remarks and Observations, p 35.

Table 7
Initial Properties of PUF Roofing Materials

Property	Specified Value	Test Method	Fort Benning	Fort Knox	Fort Lewis
Density, lb/cu ft	2.7-3.5	ASTM D 1622	Average Range	3.11 2.92 to 3.40	3.07 2.89 to 3.31
Compressive strength, lb/sq in.	40 min	ASTM D 1621	Average Range	62 51 to 76	39 35 to 41
Tensile interlaminar ⁴ strength, lb/sq in.		USBR	Average Range	64 50 to 93	55 42 to 64
Water absorption ⁵ , g/m ² surface area		ASTM D 2842	Average Range	30 27 to 33	49 46 to 54
Foam water vapor transmission (perms)		ASTM C 355	Average Range	0.86 0.83 to 0.89	1.28 0.85 to 1.65
Closed cell content of foam (percent)		ASTM D 2856	Average Range	98.0 97.1 to 99.3	96.0 95.4 to 98.4
			Average Range	94.7 94.3 to 95.7	91.4 90.3 to 91.9
Dimensional stability ⁴ of foam, percent change in linear dimension		ASTM D 2126	Average Range	0.15 -0.59 to +0.15	+0.56 0.10 to 1.23
	Perpendicular to rise 30 percent RH		Average Range	-0.03 -0.24 to +0.30	+1.19 0.59 to 1.74
	14 days		Average Range	-0.04 -0.59 to +0.49	+1.13 0.38 to 1.45
	1 day		Average Range	+0.11 -0.74 to +0.36	-0.24 -0.28 to -0.20
	7 days		Average Range	0.0 -0.39 to +0.10	-0.25 -0.39 to -0.10
	Parallel to rise 30 percent RH		Average Range	-0.39 -0.59 to +0.06	-0.03 -0.39 to +0.34
	14 days		Average Range	-0.16 -0.59 to +0.06	-0.03 -0.39 to +0.34

*Numbers refer to Remarks and Observations, p 35.

Table 7 (Cont'd)

Property	Specified Value	Test Method	Location	
			Fort Benning	Fort Knox
Perpendicular to rise 100 percent RH	1 day	Average Range	6.74	4.36
	7 days	Average Range	4.76 to 7.79	2.25 to 6.28
	14 days	Average Range	7.89	4.60
		Average Range	5.78 to 9.32	2.84 to 6.97
		Average Range	8.27	5.61
		Average Range	6.13 to 9.61	3.47 to 7.17
Parallel to rise 100 percent RH	1 day	Average Range	0.89	+0.04
	7 days	Average Range	0.53 to 1.25	-0.05 to +0.15
	14 days	Average Range	0.88	+0.39
		Average Range	0.77 to 1.07	-0.0 to +0.44
		Average Range	0.97	+0.65
		Average Range	0.71 to 1.24	-0.49 to +0.84
Coating thickness, (mils)	20 min.	USBR	30	37
Coating brittle temperature, °F	Coldest available temperature shown	ASTM D 2137 Typical	Below -104	Below -98
Indentation strength, lb/sq in.	Yield	USBR	68	78
	Coating break		46 to 82	62 to 89
			79	84
			72 to 85	81 to 105
Impact strength, grams	Top	USBR	210	370
	Base		194 to 225	328 to 418
Coating vapor ^{6*} transmission, perms	3.5 max.	ASTM E 96 Procedure B	2.2	2.4
			2.0 to 2.4	2.4 to 2.4
Coating adhesion, ^{7*} lb/sq in.		NCEL	160	198
			123 to 192	169 to 232
Coating glass ^{8*} transition, °F	Top	ASTM D 3418	-189	-189
	Base		-190 to -188	-190 to -188
				+51
				50 to 52
				-67
				-69 to -65

*Numbers refer to Remarks and Observations, p 35.

**Manufacturer's published specification.

Table 8
PUF Roofing—Physical Properties for Initial and Aged Characteristics

Property ^{3*}	Test Method	Fort Benning				
		0	12	18	24	30
Density, lb/cu ft	ASTM D 1622	Average Range 2.87 2.77 to 3.04	3.45 3.16 to 3.81	3.50 3.33 to 3.37	3.38 3.36 to 3.45	3.46 3.11 to 3.71
Compressive strength, lb/sq in.	ASTM D 1621	Average Range 53 44 to 58	71 68 to 76	59 53 to 63	54 34 to 63	59 48 to 64
Indentation strength, lb/sq in.	USBR	Average Range 68 46 to 82	91 72 to 111	100 97 to 104	90 80 to 98	89 71 to 102
Coating break		Average Range 79 72 to 85	126 114 to 138	144 132 to 155	117 107 to 125	114 99 to 123
Impact strength, grams	USBR	Average Range 210 194 to 225	535 430 to 730	394 260 to 500	453 330 to 560	420 400 to 440
Tensile interlaminar ^{4*} strength, lb/sq in.	USBR	Average Range 78 69 to 89	42 18 to 68	67 24 to 100	60 44 to 89	54 36 to 75
Water absorption, ^{5*} g/m ² surface area	ASTM D 2842	Average Range 48 43 to 53	57 51 to 63	47 42 to 51	48 43 to 53	47 45 to 49
Coating vapor ^{6*} transmission, perms	ASTM E 96 Procedure B	Average Range 2.2 2.0 to 2.4	2.0 1.3 to 2.9	2.1 1.9 to 2.3	6*	1.3 1.1 to 1.6
Coating adhesion, ^{7*} lb/sq in.	NCEL	Average Range 160 123 to 192	130 83 to 184	111 74 to 158	115 105 to 124	118 115 to 120
Coating glass ^{8*} transition, °F	ASTM D 3418	Average Range -189 -190 to -188	-186 -187 to -185	-185 -186 to -184	-186 -187 to -185	-183 -184 to -182

*Numbers refer to Remarks and Observations, p 35.

Table 9
PUF Roofing—Physical Properties for Initial and Aged Characteristics

Fort Knox			Age-Months	
Property ^{3*}		Test Method	0	24
Density, lb/cu ft		ASTM D 1622	Average Range	3.11 2.92 to 3.40
Compressive strength, lb/sq in.		ASTM D 1621	Average Range	62 51 to 76
Indentation strength, lb/sq in.	Yield	USBR	Average Range	78 62 to 89
	Coating break		Average Range	136 134 to 138
			Average Range	144 132 to 155
			Average Range	84 81 to 105
Impact strength, grams		USBR	Average Range	370 328 to 418
Tensile interlaminar ^{4*} strength, lb/sq in.		USBR	Average Range	64 50 to 93
Water absorption ^{5*} g/m ² surface area		ASTM D 2842	Average Range	30 27 to 33
Coating vapor ^{6*} transmission, perms		ASTM E 96 Procedure B	Average Range	2.4 2.4 to 2.4
Coating adhesion, ^{7*} lb/sq in.		NCEL	Average Range	156 130 to 181
Coating glass ^{8*} transition, °F		ASTM D 3418	Average Range	-189 -190 to -188

*Numbers refer to Remarks and Observations, p 35.

Table 10
PUF Roofing—Physical Properties for Initial and Aged Characteristics

Property ^{3*}	Test Method	Fort Lewis				
		0	12	18	24	
Density, lb/cu ft	ASTM D 1622	Average Range	3.07 2.89 to 3.31	3.05 2.93 to 3.31	2.94 2.73 to 3.23	
Compressive strength, lb/sq in.	ASTM D 1621	Average Range	39 35 to 41	40 38 to 43	38 36 to 48	
Indentation strength, lb/sq in.	USBR	Average Range	65 54 to 75	60 56 to 65	65 58 to 73	
Coating break		No break at Range	103 ½-in. deflection	130 116 to 142	100 98 to 120	
Impact strength, grams	USBR	Average Range	140 120 to 192	No separate break visible		
		Average Range	650 623 to 675	323 140 to 460	335 270 to 400	
Tensile interlaminar ^{4*} strength, lb/sq in.	USBR	Average Range	55 42 to 64	72 48 to 87	81 78 to 83	
Water absorption, ^{5*} g/m ² surface area	ASTM D 2842	Average Range	49 45 to 54	36 30 to 43	44 41 to 46	
Coating vapor ^{6*} transmission, perms	ASTM E 96 Procedure B	Average Range	1.6 0.8 to 2.4	6* 6*	1.3 1.1 to 1.5	
Coating adhesion, ^{7*} lb/sq in.	NCEL	Average Range	174 157 to 192	190 170 to 209	168 150 to 186	
Coating glass ^{8*} transition, ° F	ASTM D 3418	Average Range	+51 50 to 52	+55 53 to 57	+61 58 to 63	
		Average Range	-67 -69 to -65	-64 -65 to -63	Unable to obtain specimen	

*Numbers refer to Remarks and Observations, p 35.

Table 11
Initial Properties of BUR Materials

Property	Test Method	ASTM Spec. Requirements	Location	
			Fort Benning	Fort Lewis
Assembly characteristics				
Average number of plies	ASTM D 3617-77		4.2	3.2
Membrane mass, lb/100 sq ft			173.	251.
Asphalt mass, lb/100 sq ft			123.	211.
Lap spacing, average			7.5	11.0
Roof surfacing characteristics				
Hardness, percent loss after tumbling	ASTM D 1863-77	Max 20	9.	N/A
Unit weight, lb/cu ft		Min 60	97.8	N/A
Gradation, percent passing		100	100.0	N/A
3/4 in.		90 to 100	82.8	N/A
1/2 in.		40 to 70	25.2	N/A
3/8 in.		0 to 15	0.6	N/A
No. 4		0 to 5	N/A	
No. 8			0.3	N/A
Roofing felt characteristics				
Breaking strength, lb/in. width	ASTM D 226-77 at Benning, ASTM D 2178-76 at Lewis	Benning	8.4	35.6
		Min 30	8.0	29.0
Pliability at 77°F, (1/2-in. radius)		Min 15	Pass	Pass
Openness of perforations, percent		Min 30	100	N/A
Loss on heating at 105°C, 5 hours, percent		Max 4	6.0	N/A
Weight, lb/100 sq ft		Min 13	11.9	12.2
Holes/sq ft		Min 115	144.	N/A
Asphalt characteristics				
Flash point (COC), °F	ASTM D 312-78	Min 437	585.	580.
Softening point, °F		185 to 205	195.	194.
Penetration at 77°F		15 to 35	17.	13.
Penetration at 115°F		Max 90	32.	31.
Solubility in TCE, %		Min 99	99.8	99.8
Ductility at 77°F, cm		Min 2.5	4.	4.

Note: See Remark No. 10, p 35.

Table 12
Roof Surface Temperatures

Date	Time	Min.	Max.	Avg.	Dev.	90% Confidence Interval
Fort Lewis						
8-11-81	0000					
	PUF	55.0	65.0	59.0	2.6	(57.4, 60.6)
	BUR	59.0	65.0	62.1	2.5	(60.5, 63.7)
	EPDM	56.0	62.0	59.3	1.8	(58.2, 60.4)
	1200					
	PUF	139.0	160.0	151.1	7.2	(146.7, 155.5)
	BUR	128.0	167.0	146.0	11.8	(138.4, 153.6)
	EPDM	141.0	160.0	154.2	6.7	(150.1, 158.3)
	0000					
	PUF	40.0	49.0	44.0	2.4	(42.6, 45.4)
9-11-81	BUR	40.0	48.0	43.9	2.8	(42.1, 45.7)
	EPDM	39.0	45.0	43.2	1.9	(42.1, 44.3)
	1200					
	PUF	112.0	133.0	125.1	7.2	(120.8, 129.4)
	BUR	99.0	145.0	121.6	13.3	(113.0, 130.2)
	EPDM	110.0	136.0	128.5	6.7	(124.5, 132.5)
	0000					
	PUF	30.0	42.0	37.9	5.0	(34.9, 40.9)
	BUR	41.0	43.0	42.0	.5	(41.7, 42.3)
	EPDM	41.0	41.0	41.0	.0	(41.0, 41.0)
11-29-81	1200					
	PUF	49.0	62.0	57.8	4.2	(55.3, 60.3)
	BUR	48.0	60.0	53.2	3.5	(51.0, 55.3)
	EPDM	56.0	60.0	58.2	1.7	(57.2, 59.2)
	0000					
	PUF	28.0	35.0	31.0	2.2	(29.8, 32.4)
	BUR	28.0	34.0	31.4	2.3	(30.0, 32.9)
	EPDM	25.0	34.0	30.1	2.3	(28.7, 31.5)
	1200					
	PUF	78.0	94.0	88.0	4.8	(85.1, 90.9)
4-25-82	BUR	73.0	99.0	85.7	7.4	(80.9, 90.4)
	EPDM	78.0	95.0	89.7	4.5	(87.0, 92.4)
	0000					
	BUR	70.0	79.0	73.9	3.0	(71.7, 76.0)
	EPDM	70.0	74.0	71.9	1.2	(71.2, 72.5)
	1200					
	BUR	88.0	108.0	100.9	6.3	(96.4, 105.4)
	EPDM	108.0	194.0	173.5	21.1	(163.2, 183.8)
	0000					
	BUR	59.0	64.0	60.9	2.2	(59.3, 62.5)
10-23-81	EPDM	56.0	60.0	57.6	1.0	(57.1, 58.2)
	1200					
	BUR	66.0	69.0	67.8	1.0	(67.1, 68.4)
	EPDM	71.0	84.0	78.3	3.7	(76.5, 80.1)

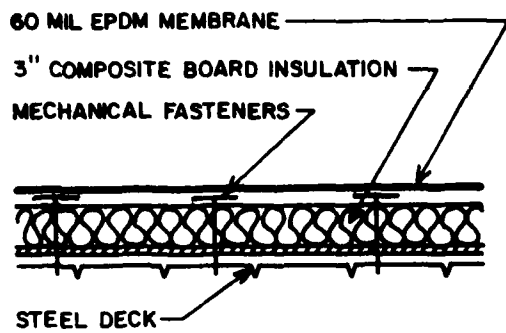
Table 12 (Cont'd)

Date	Time	Min.	Max.	Avg.	Dev.	90% Confidence Interval
1-10-82	0000					
	BUR	40.0	47.0	44.1	2.6	(42.2, 46.0)
	EPDM	34.0	46.0	39.3	3.7	(37.5, 41.1)
	1200					
	BUR	25.0	41.0	34.0	5.7	(29.9, 38.1)
	EPDM	30.0	89.0	66.9	17.1	(58.5, 75.2)

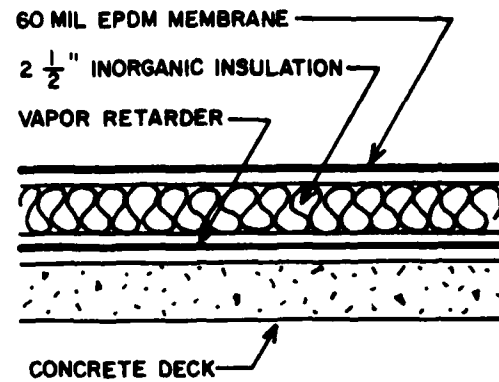
REMARKS AND OBSERVATIONS FOR TABLES 4 THROUGH 10*

1. The 14-day 100 percent relative humidity dimensional stability results at Fort Lewis are generally lower than might be expected. While some consolidation could have occurred during the process of stabilizing after such large expansion, the magnitude of difference suggests some relative humidity drop during the 7- to 14-day interval.
2. No significant change (visual) in EPDM rubber or polyurethane foam specimens has occurred during outdoor exposure at Denver or Xenon arc accelerated aging. Outdoor exposure was started in August 1980 and now has an age of 32 months. Xenon arc exposure was started March 1981 and now has an age of 4024 hours.
3. Fort Benning and Fort Knox aged foam samples differ from the original, but Fort Lewis samples do not. If the original samples had been cut out of the roof instead of being sprayed into boxes, one possible reason for this difference could be eliminated.
4. The interlaminar bond strength of the Fort Benning foam is declining. These data may be of value in determining the cause of blisters if they are observed during future inspections.
5. The foam water absorption tests were conducted according to ASTM D 2842. However, under a separate program, it is intended to rerun this test using a modified procedure. Investigators hope to eliminate some of the difficulties encountered and obtain less change in dimension of specimens during water immersion by testing at less than atmospheric pressure and reducing the exposure time.
6. High water vapor transmission test results (perms) were obtained for these samples: Fort Benning-24 months, 5.7; Fort Lewis-12 months, 5.5; 18 months, 6.4. This may have resulted from holes caused by mineral granules puncturing the coating or voids left when granules were dislodged. It could also have happened either during normal roof service or during removal and shipping of samples. Observations of the samples tend to confirm this possibility. However, to be sure that no error was introduced during testing, these tests were rerun and indicated high values, although with a few lower individual results in the 3 to 5 perm range.
7. The U.S. Navy Civil Engineering Laboratory test method was used for coating adhesion, since no other standard was available and no other such data are known to be published. Values in the table reflect the adhesion strength fairly well for purposes of categorization. However, the test is operator-sensitive in terms of sample preparation and test execution.
8. The glass transition temperature appears stable for all materials, except for the Hypalon topcoat at Fort Lewis. The gradual upward shift compares with observations of early deterioration in Hypalon performance on USBR roofs.
9. No significant change, or even trend toward change, in the EPDM rubber can be established except for the shift between the original and the first 6 months of age.
10. For asphalt, the composition complexity produces an equally complex pattern of softening over a broad temperature range. This includes the beginning of thermal motion at -45°F and continues through the highest observed melting point of 135°F. Two distinct glass transition temperatures have been identified: one at -27°F and the other at 41°F. An endothermic peak (melt) regularly occurred at 57°F, and two additional peaks were found, one in the 81°F to 110°F region, and the other in the 102°F to 135°F region. Results of a large number of tests using different techniques on the differential scanning calorimeter indicate that the two resins involved at the higher temperatures are highly sensitive to their thermal history and may be more prone to interact with other elements of their compound environment. Nevertheless, no distinguishable shift has occurred during the 24-month aging.

*Remarks and observations were provided by the U.S. Bureau of Reclamation.

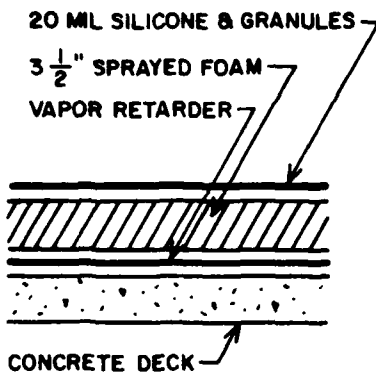


FORT BENNING

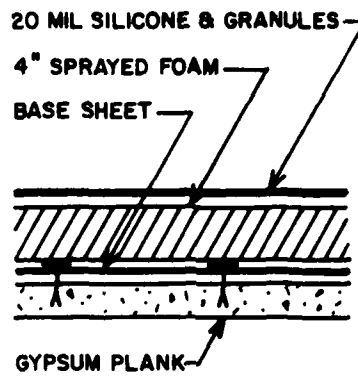


FORT LEWIS

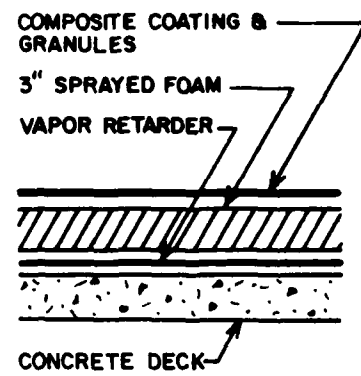
Figure 1. EPDM roofs, cross sections.



FORT BENNING

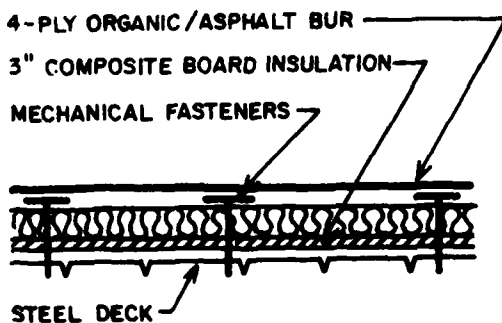


FORT KNOX

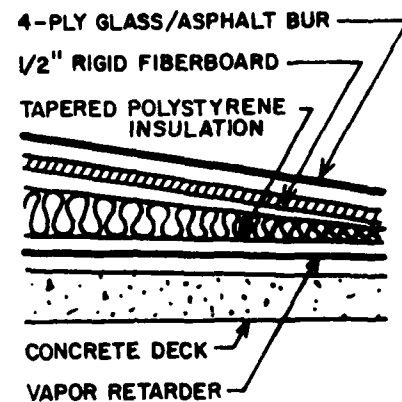


FORT LEWIS

Figure 2. PUF roofs, cross sections.

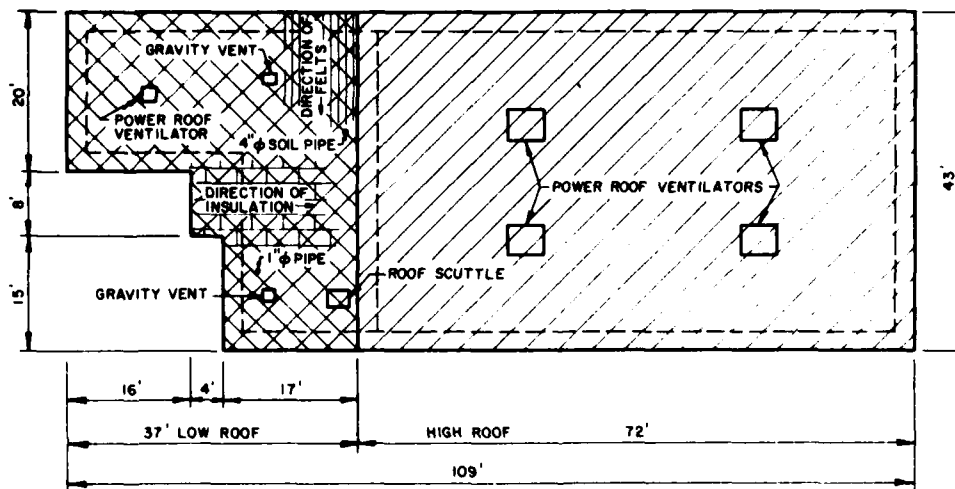


FORT BENNING





FORT LEWIS

Figure 3. BUR roofs, cross sections.



LEGEND

-  INDICATES AREA TO RECEIVE NEW EPDM ROOF
-  INDICATES AREA TO RECEIVE NEW BUILT-UP ROOF

ROOF PLAN - BLDG. 2823

Figure 4. Building selected for EPDM and BUR at Fort Benning.

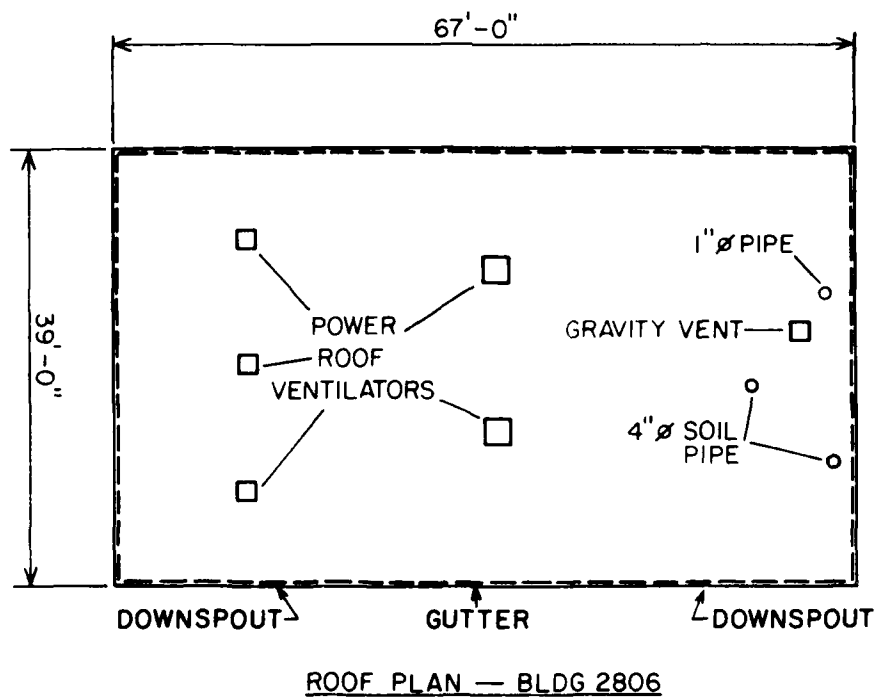
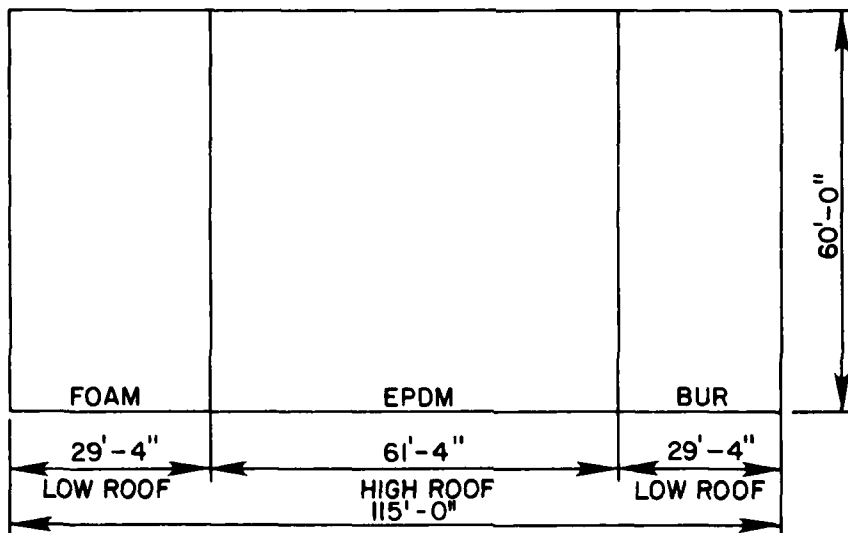
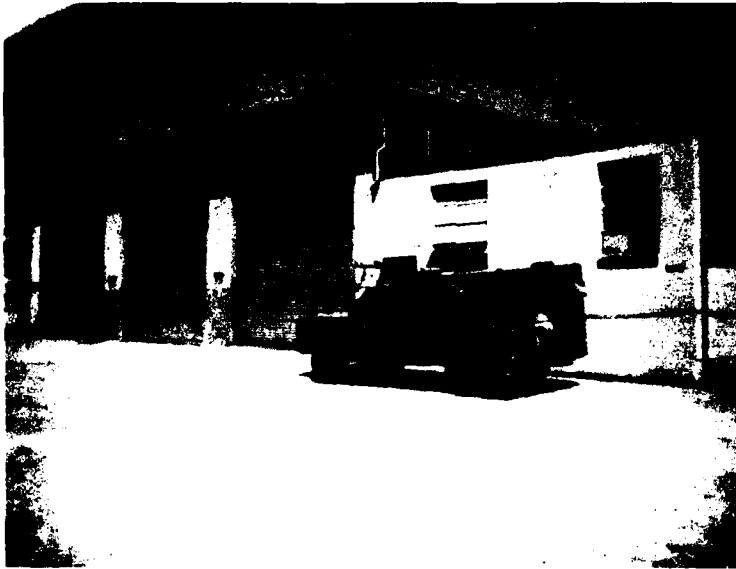


Figure 5. Building selected for PUF roofing at Fort Benning.



ROOF PLAN - BLDG 6576

Figure 6. Building selected for PUF roofing at Fort Knox.

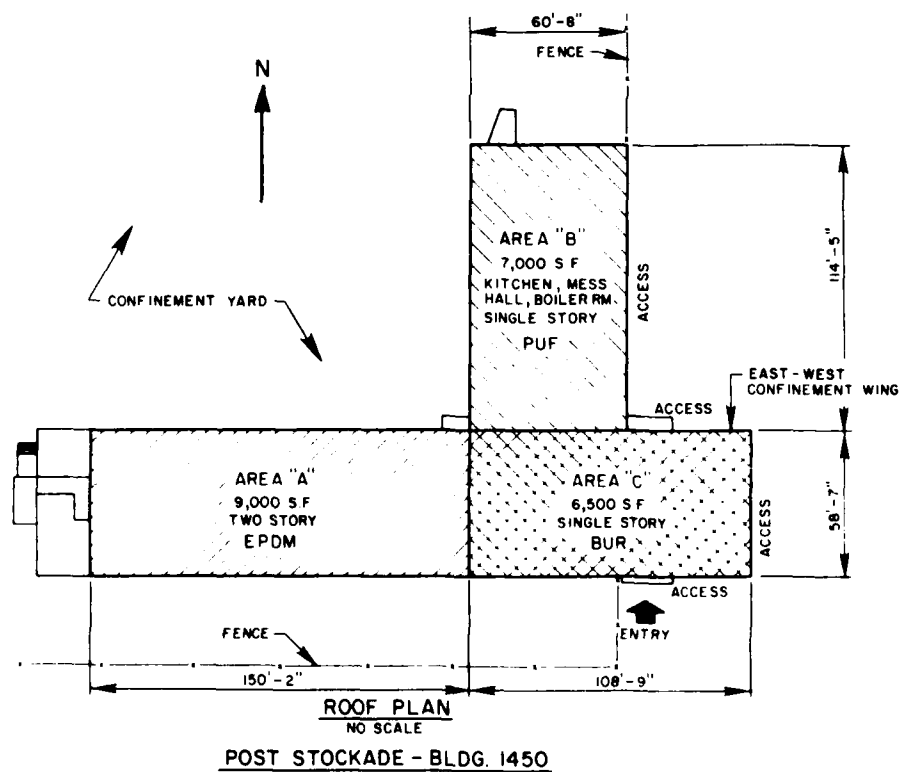


Figure 7. Building selected for EPDM, BUR, and PUF at Fort Lewis.

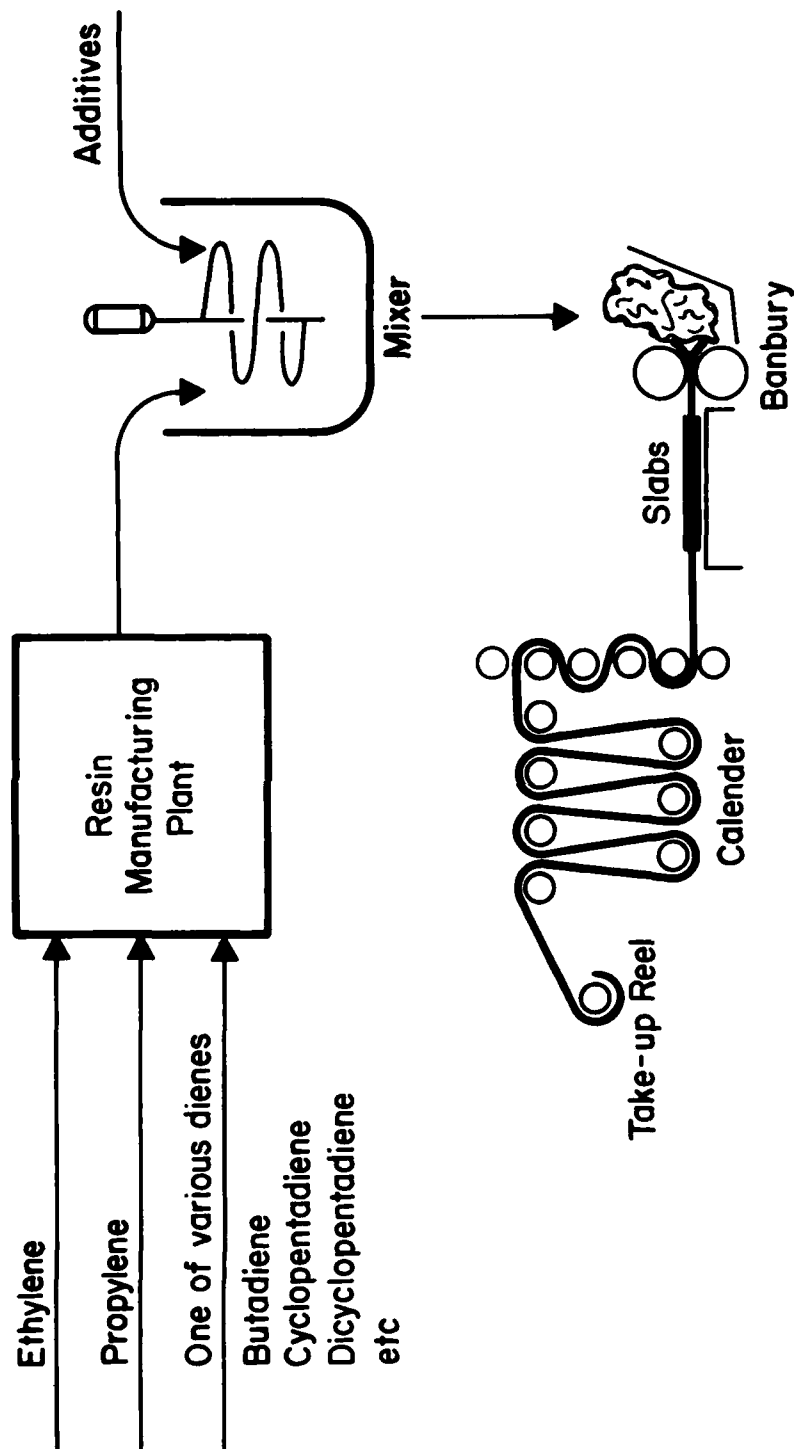


Figure 8. EPDM manufacture.



Figure 9. Typical group of EPDM sample patches.

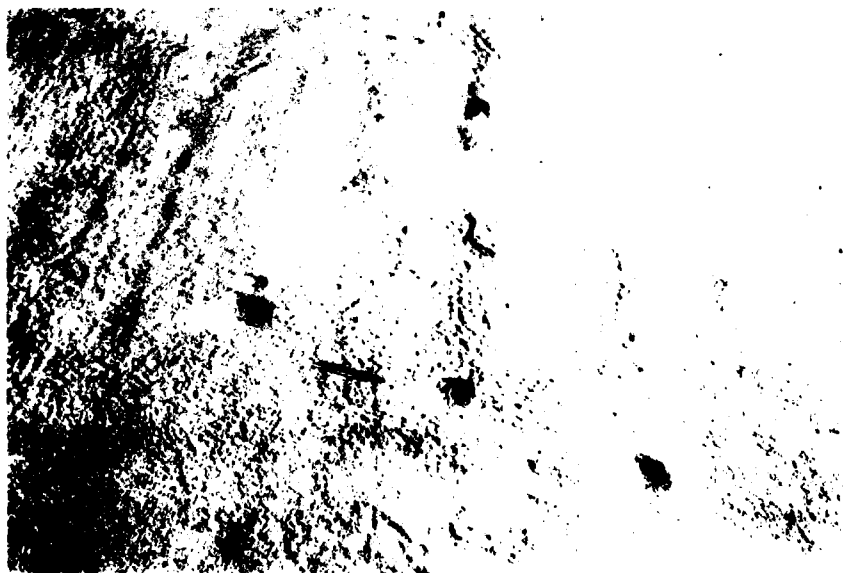


Figure 10. Interlaminar blisters in foam at Fort Knox.

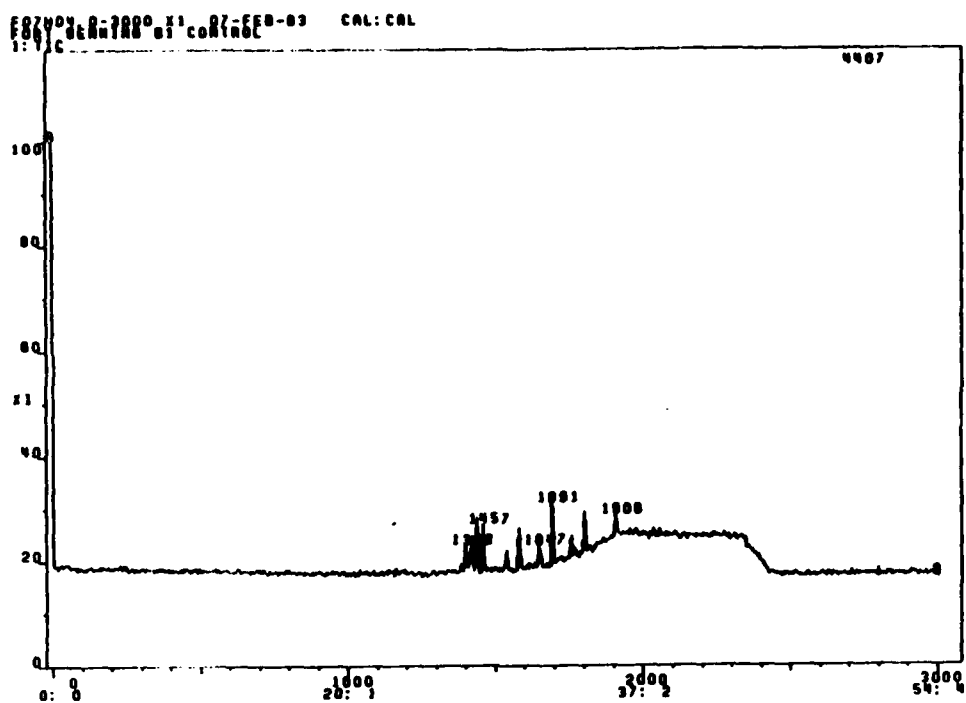


Figure 11. Fort Benning control fraction I.

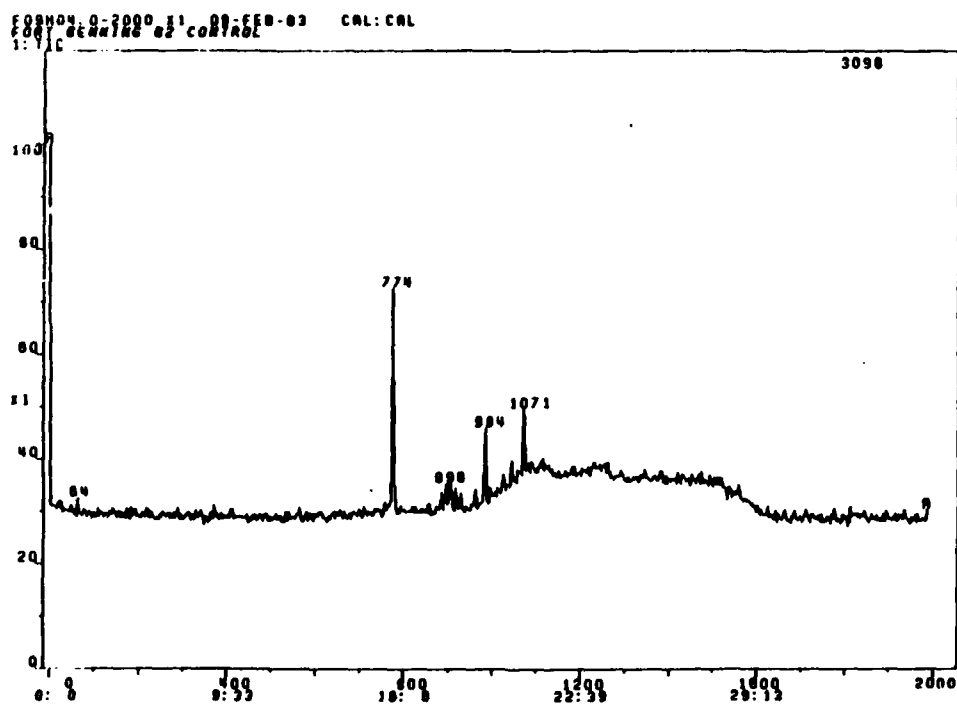


Figure 12. Fort Benning control fraction II.

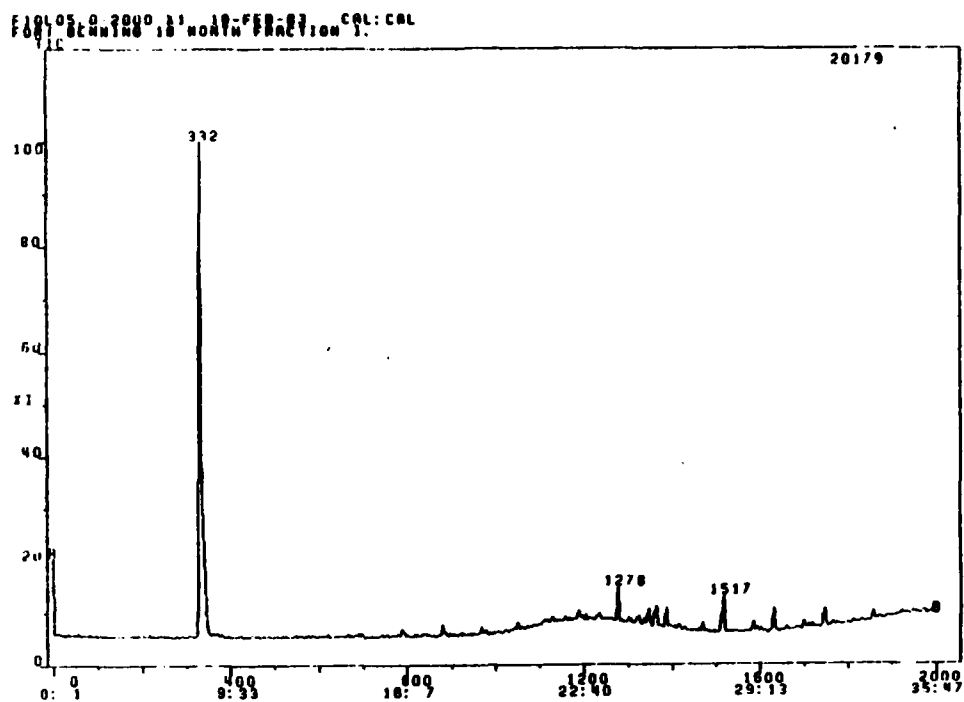


Figure 13. Fort Benning 18-month fraction I.

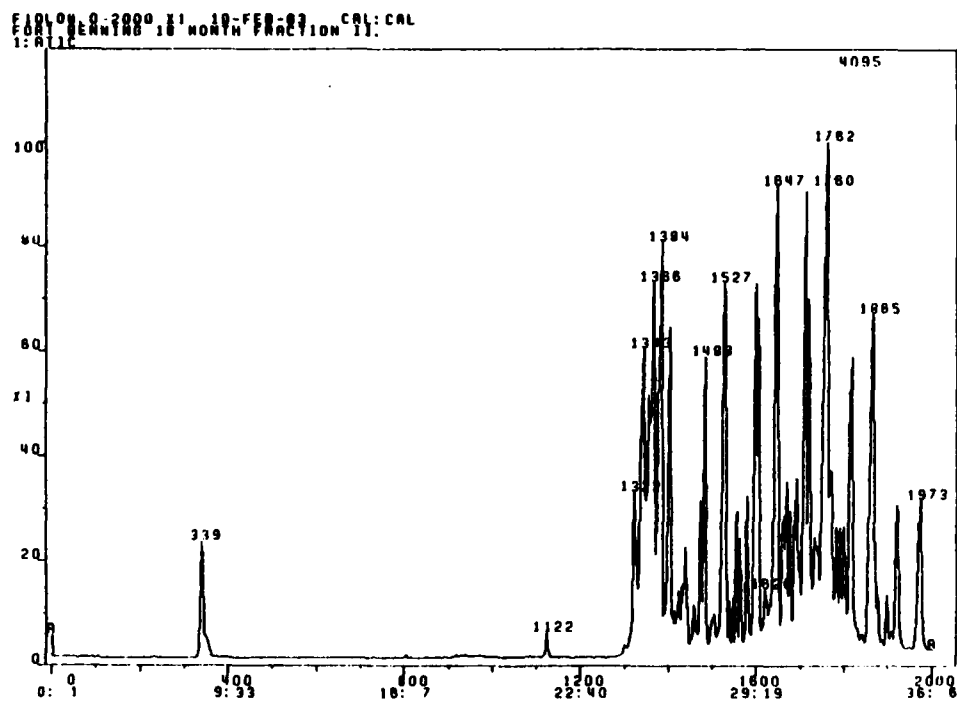


Figure 14. Fort Benning 18-month fraction II.

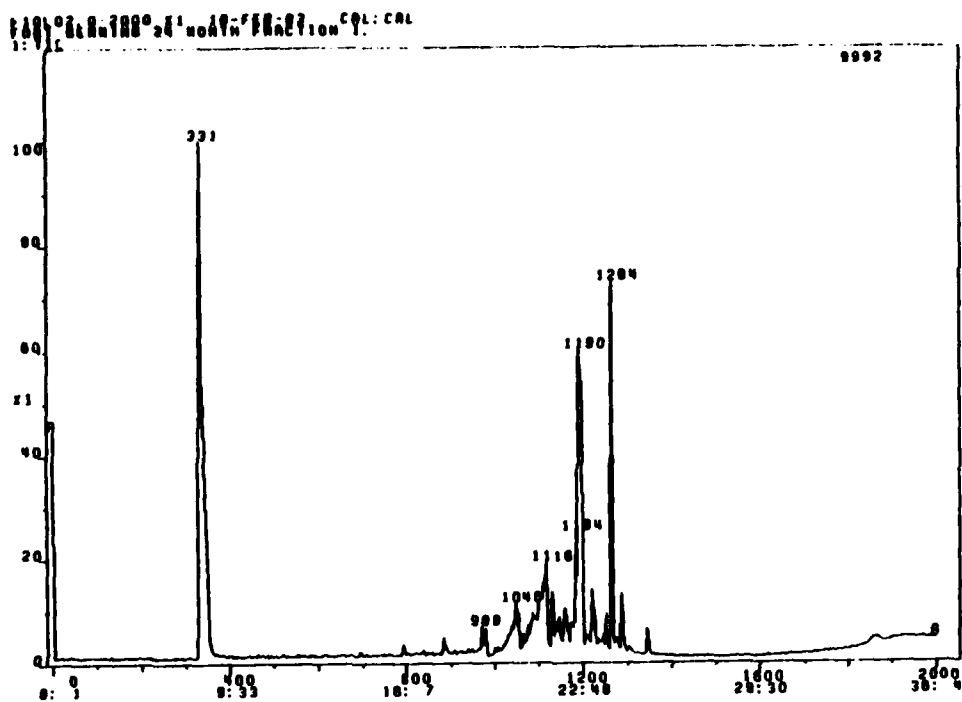


Figure 15. Fort Benning 24-month fraction I.

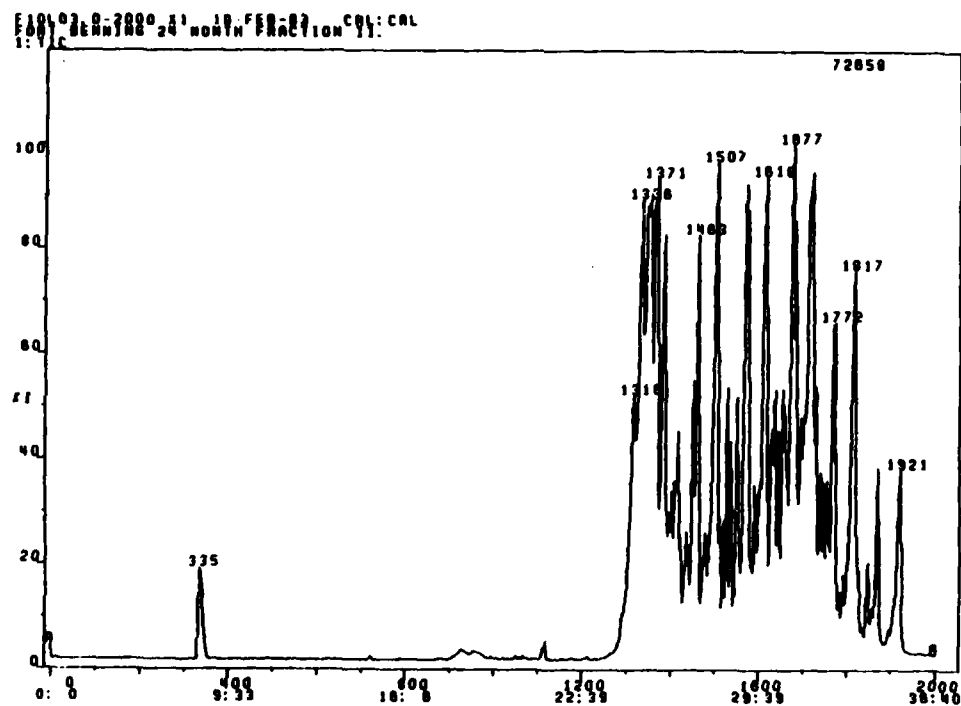


Figure 16. Fort Benning 24-month fraction II.

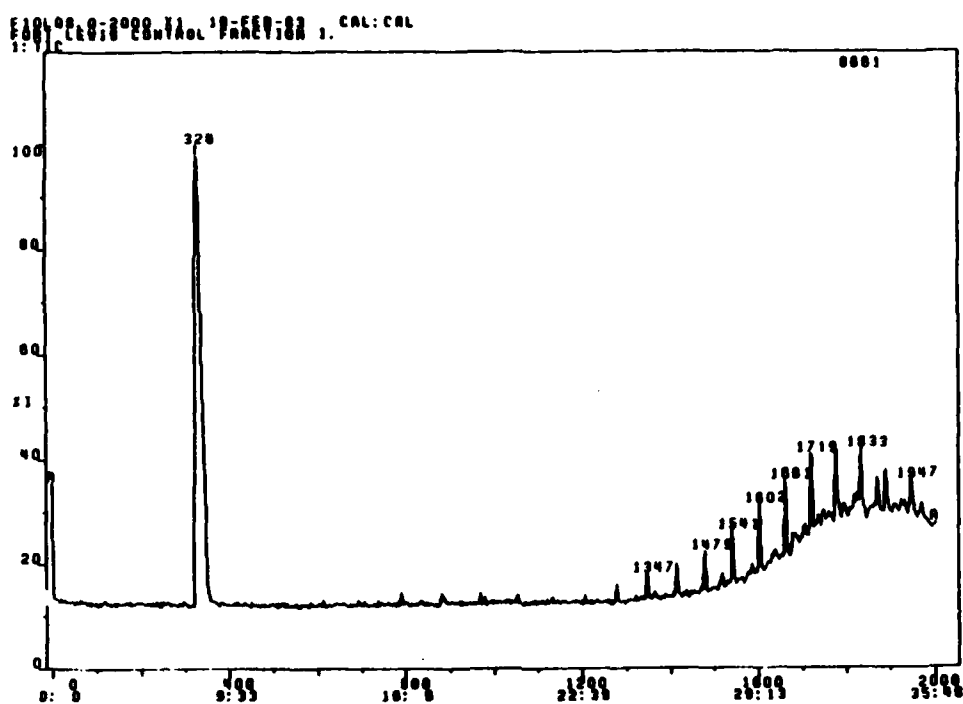


Figure 17. Fort Lewis control fraction I.

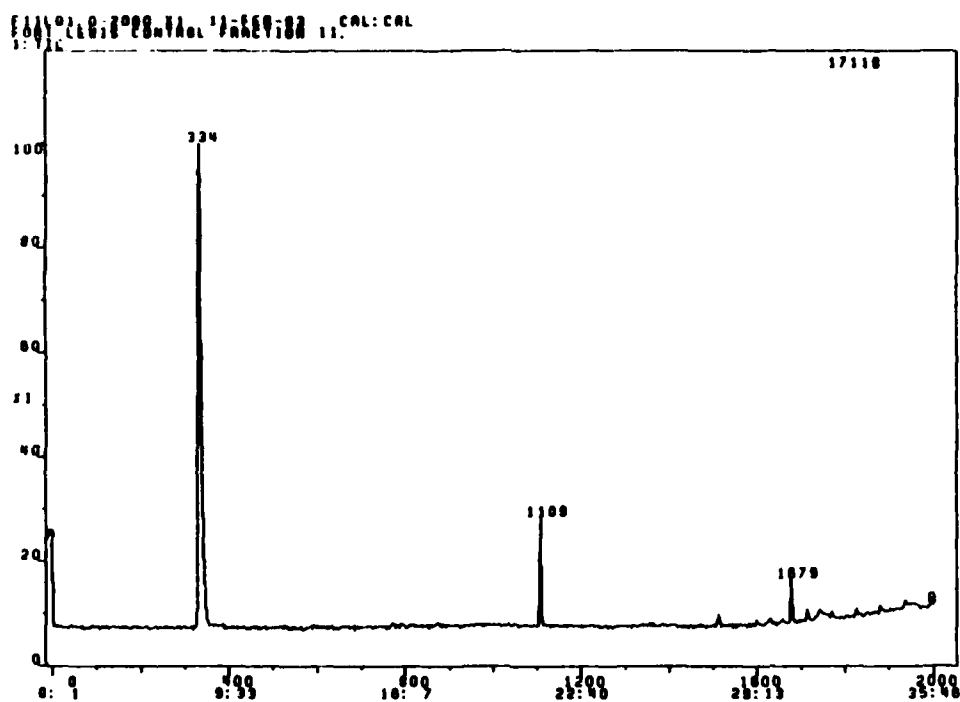


Figure 18. Fort Lewis control fraction II.

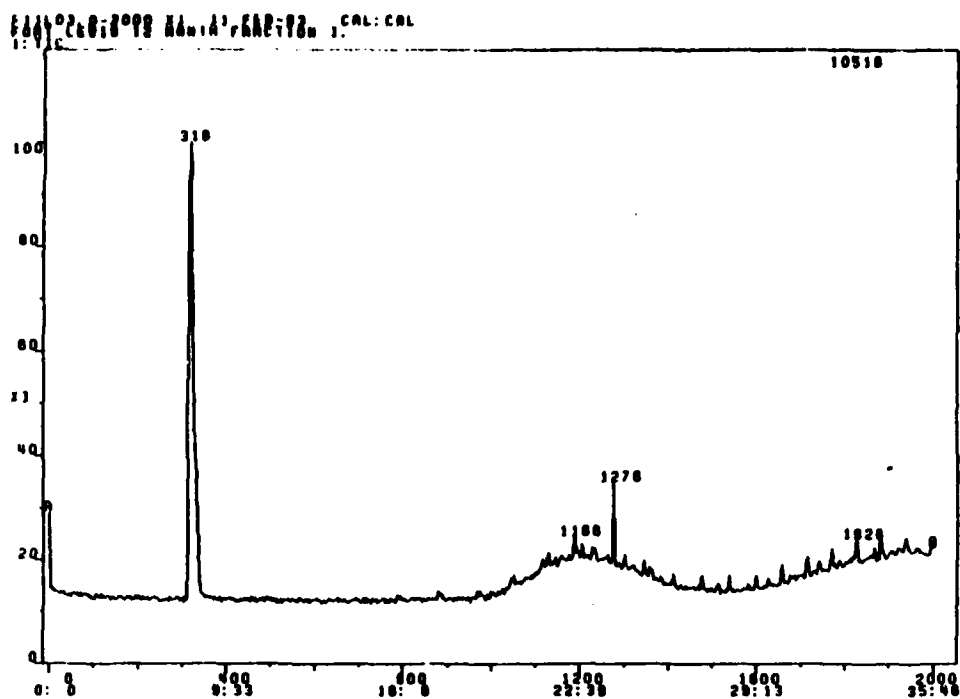


Figure 19. Fort Lewis 12-month fraction I.

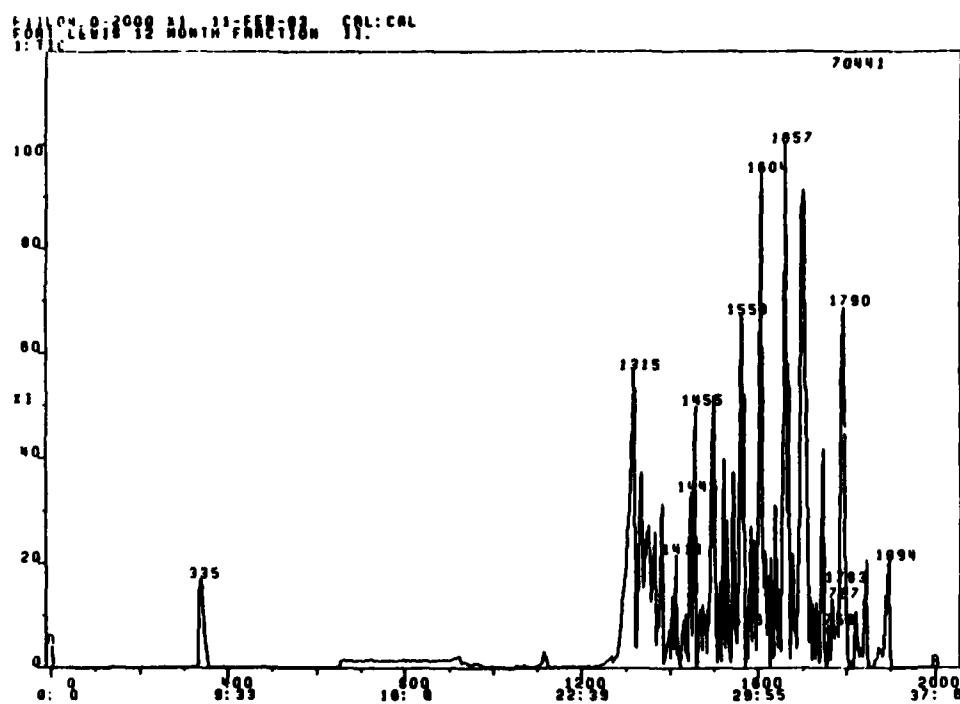


Figure 20. Fort Lewis 12-month fraction II.

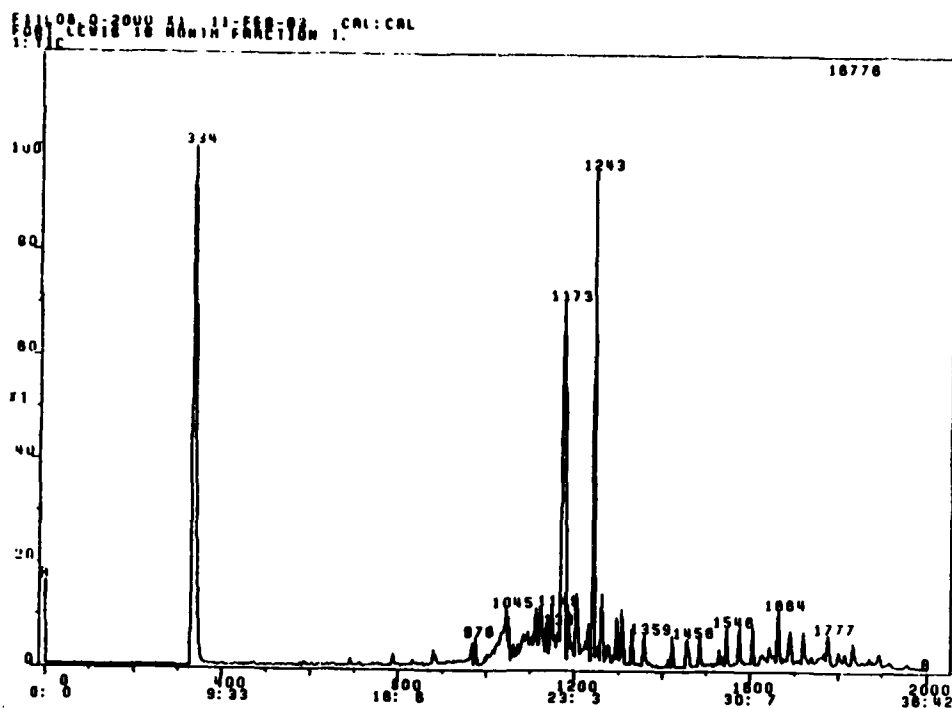


Figure 21. Fort Lewis 18-month fraction I.

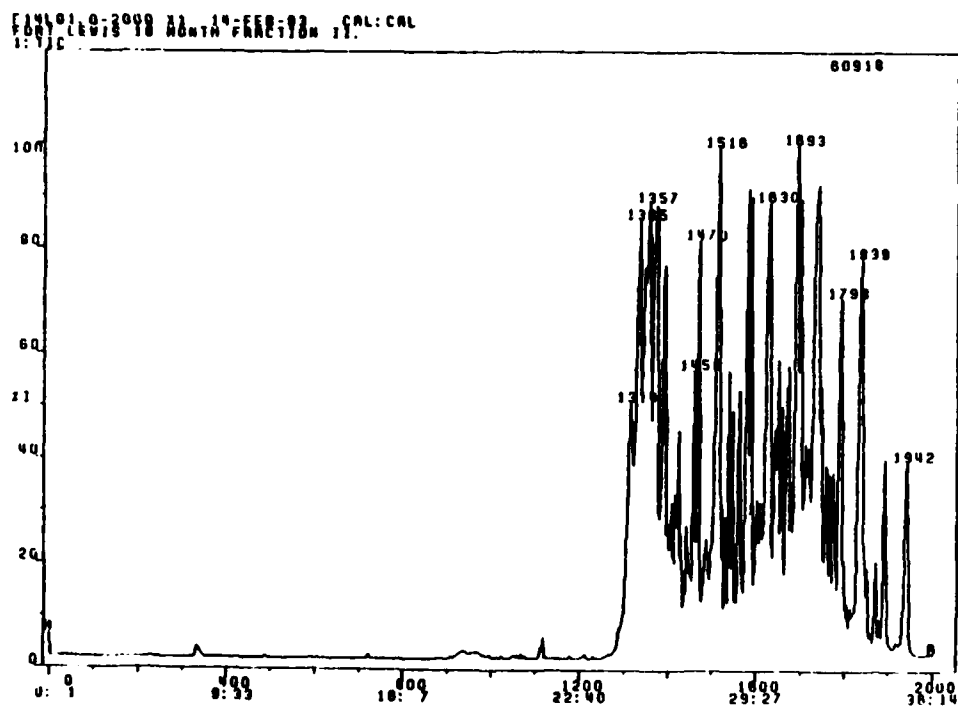


Figure 22. Fort Lewis 18-month fraction II.

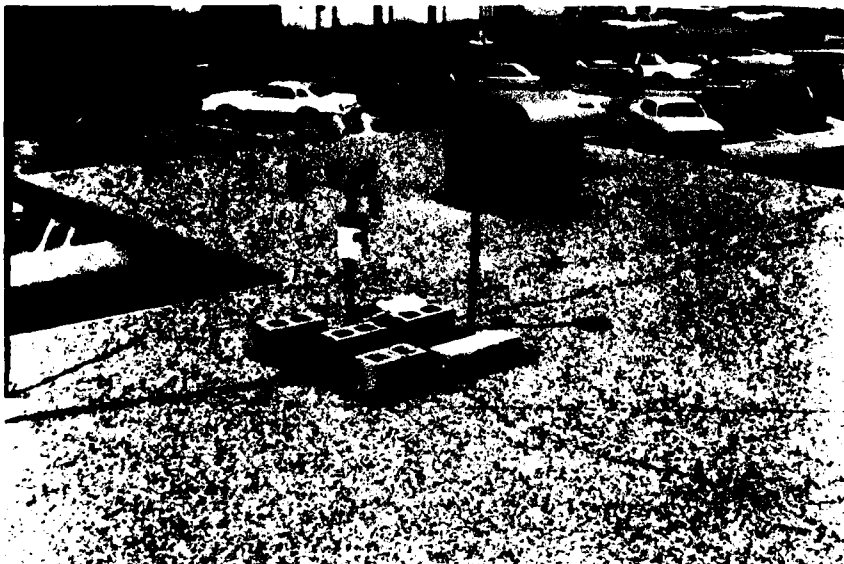
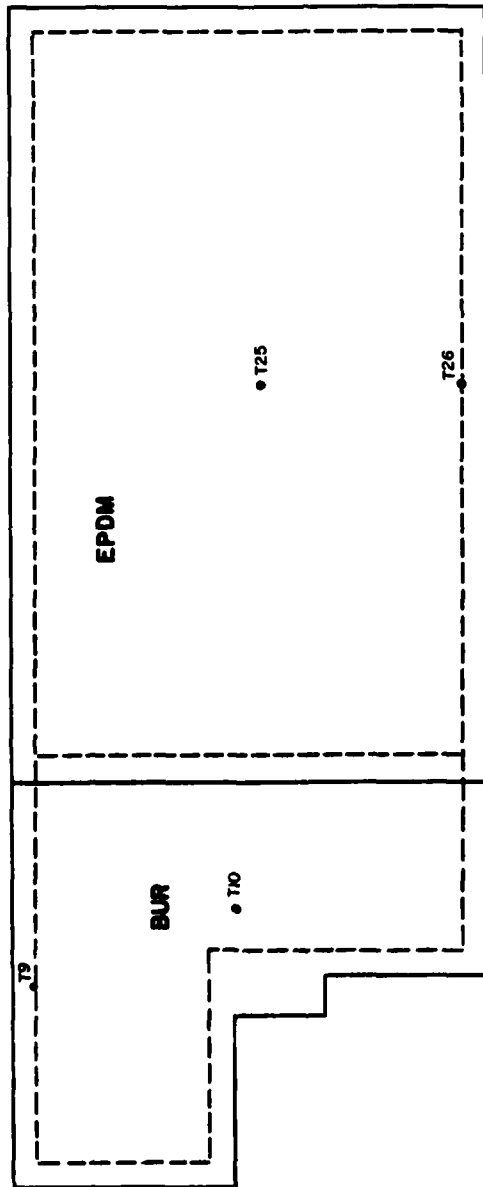
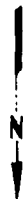


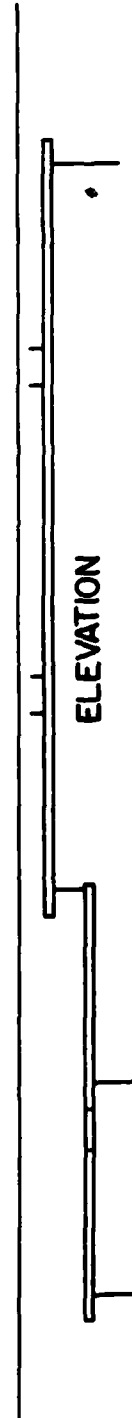
Figure 23. Weather station at Fort Benning.

THERMOCOUPLES - BELOW INSULATION

• T THERMOCOUPLE



PLAN

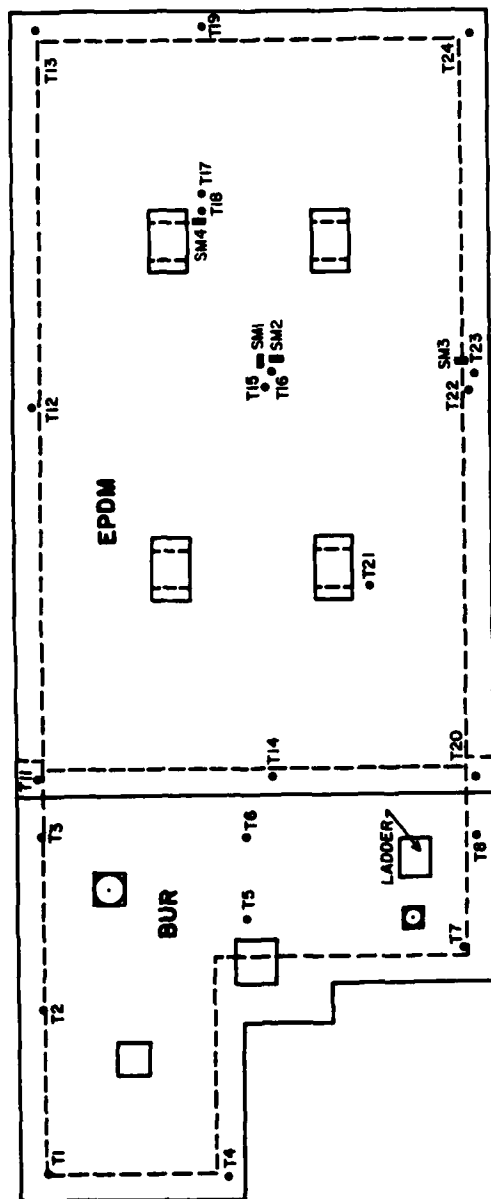


ELEVATION

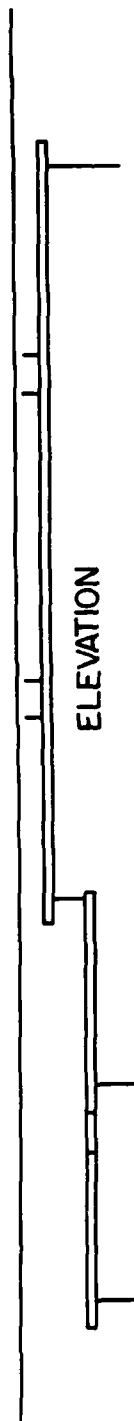
Figure 24. Thermocouples below insulation—building 2823, Fort Benning.

ALL TRANSDUCERS - TOP OF MEMBRANE

- T THERMOCOUPLE
- ▬ SM STRAIN GAGE



PLAN



ELEVATION

Figure 25. Thermocouples and strain gages on top of membranes—building 2823, Fort Benning.

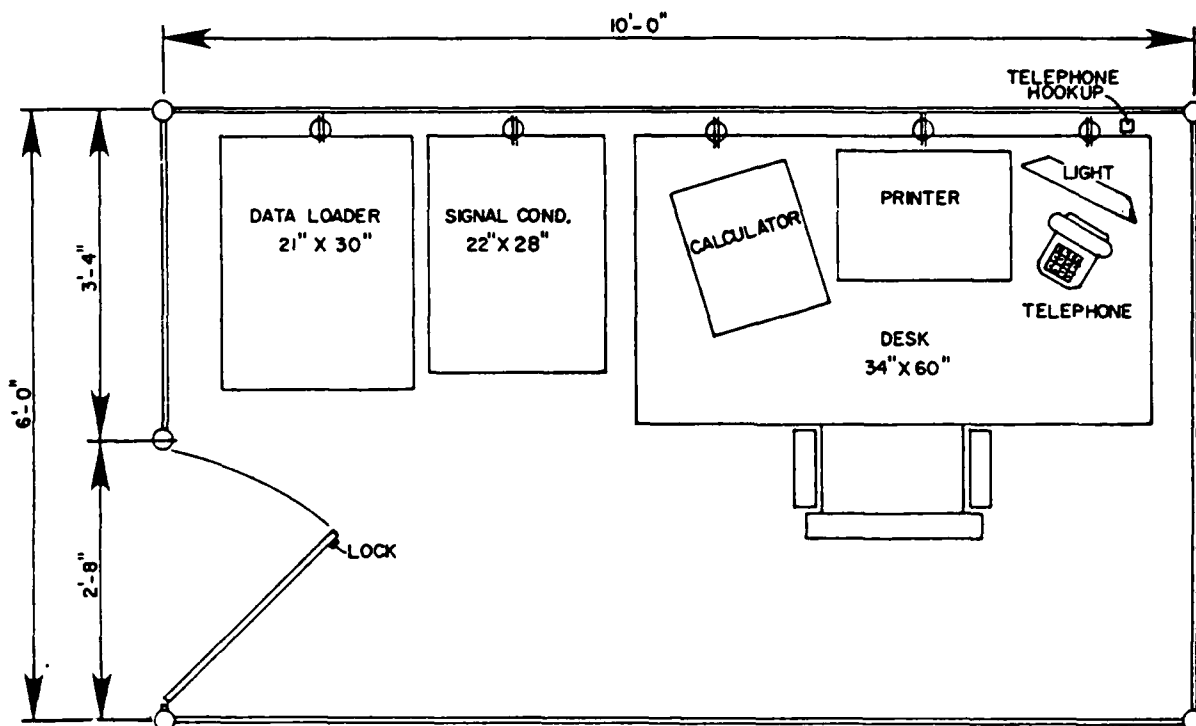


Figure 26. Data recording equipment room layout—Fort Benning.

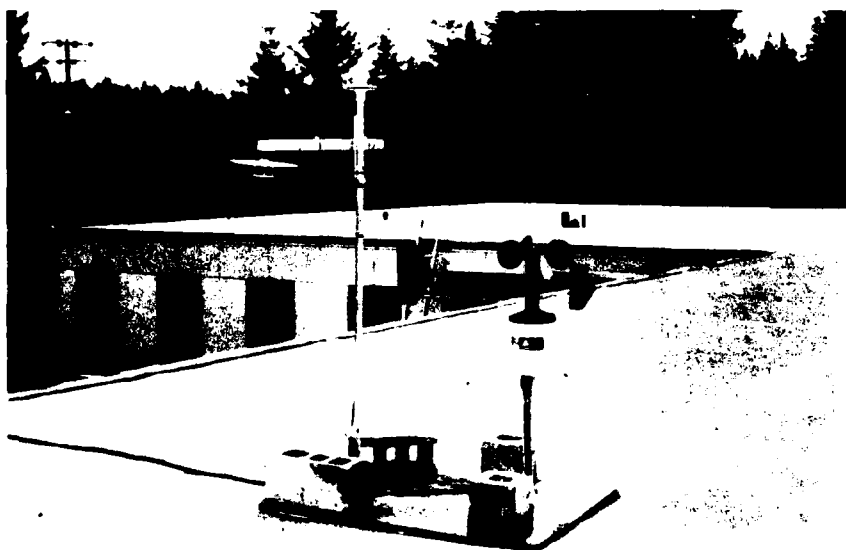
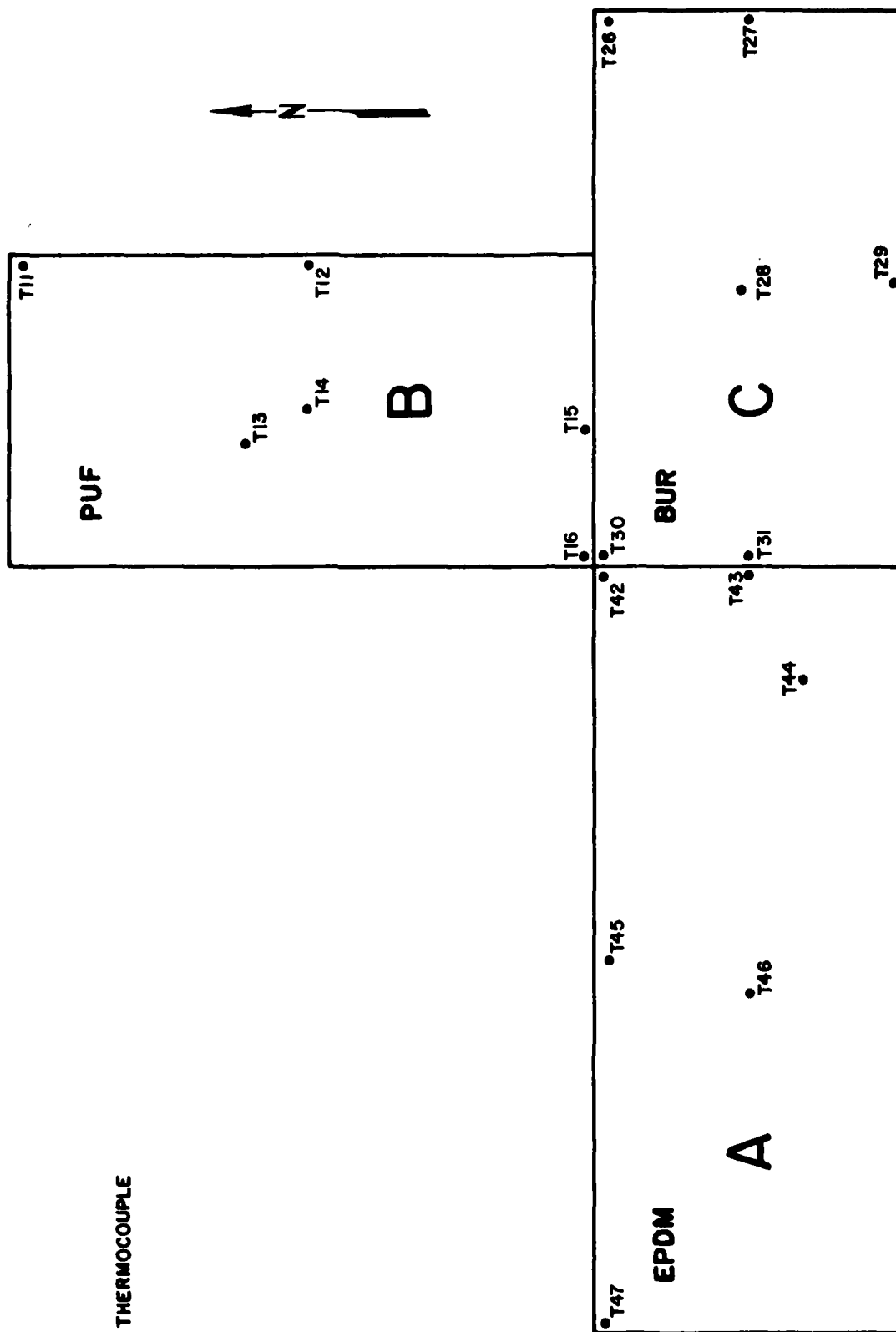


Figure 27. Weather station at Fort Lewis.



NOTE: T48 IN EQUIPMENT CABINET IN INSTRUMENTATION ROOM

Figure 28. Thermocouples below insulation—building 1450, Fort Lewis.

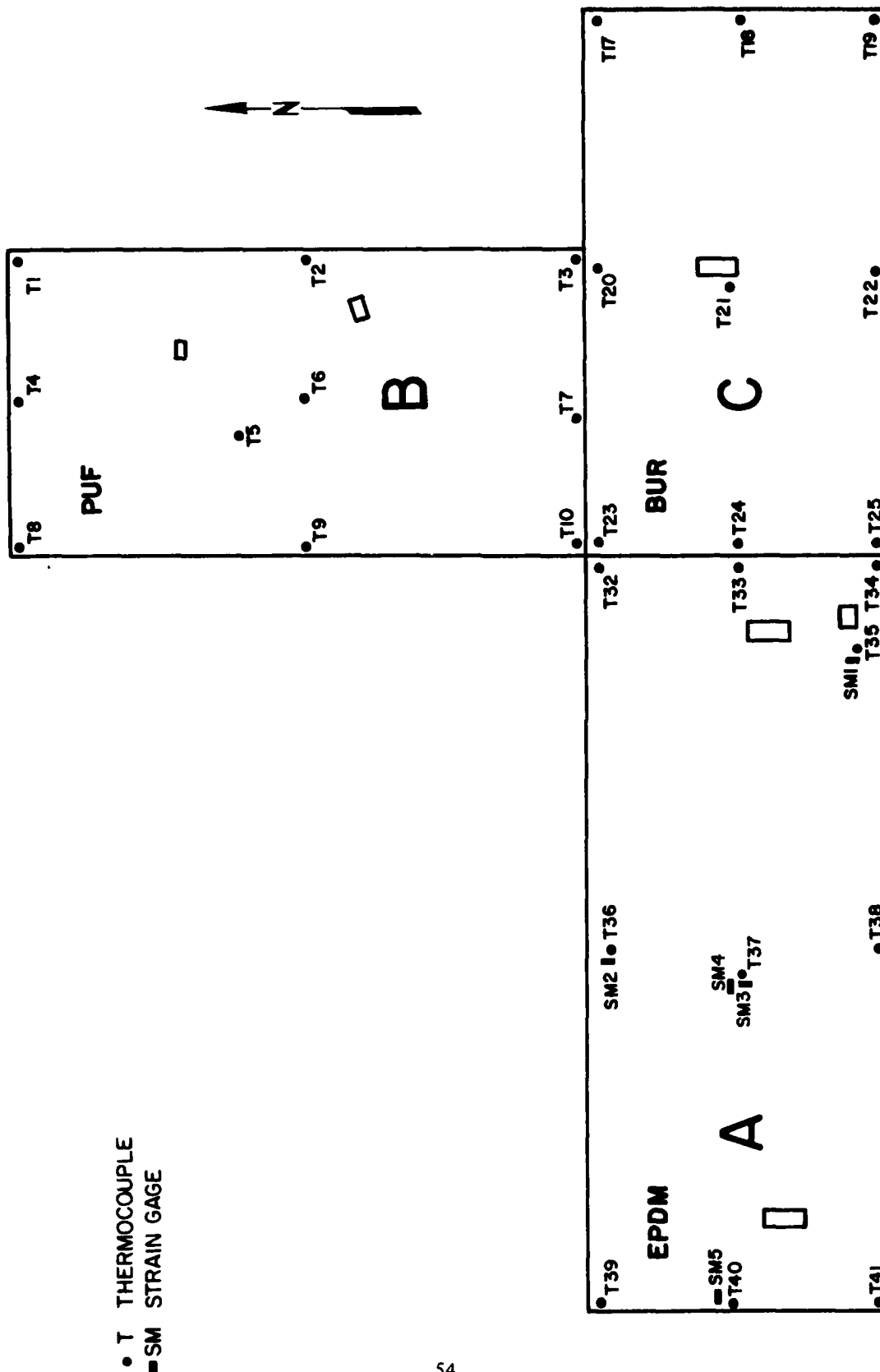


Figure 29. Thermocouples and strain gages on top of membranes—building 1450, Fort Lewis.

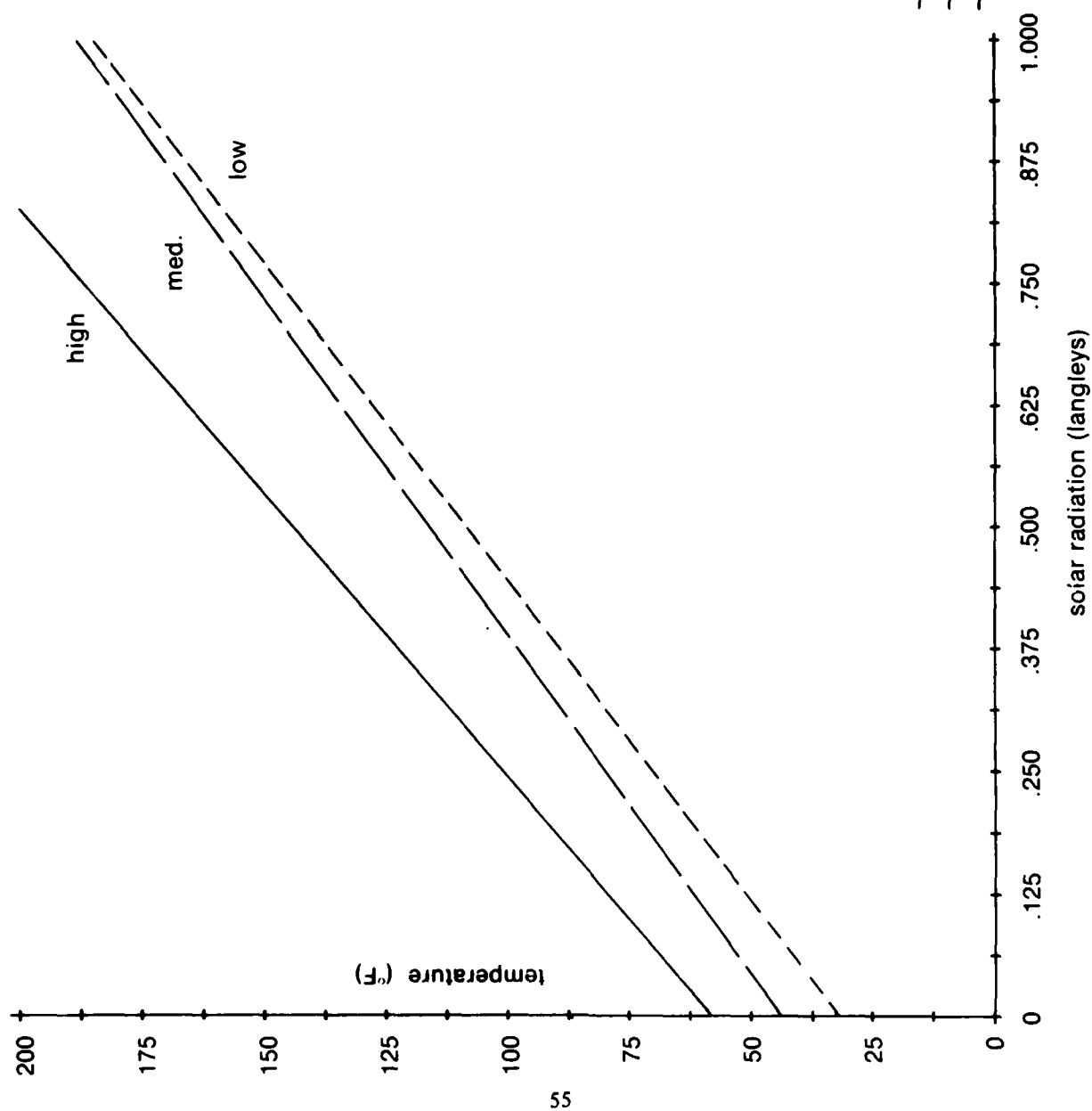


Figure 30. EPDM temperature vs. solar radiation—Fort Lewis.

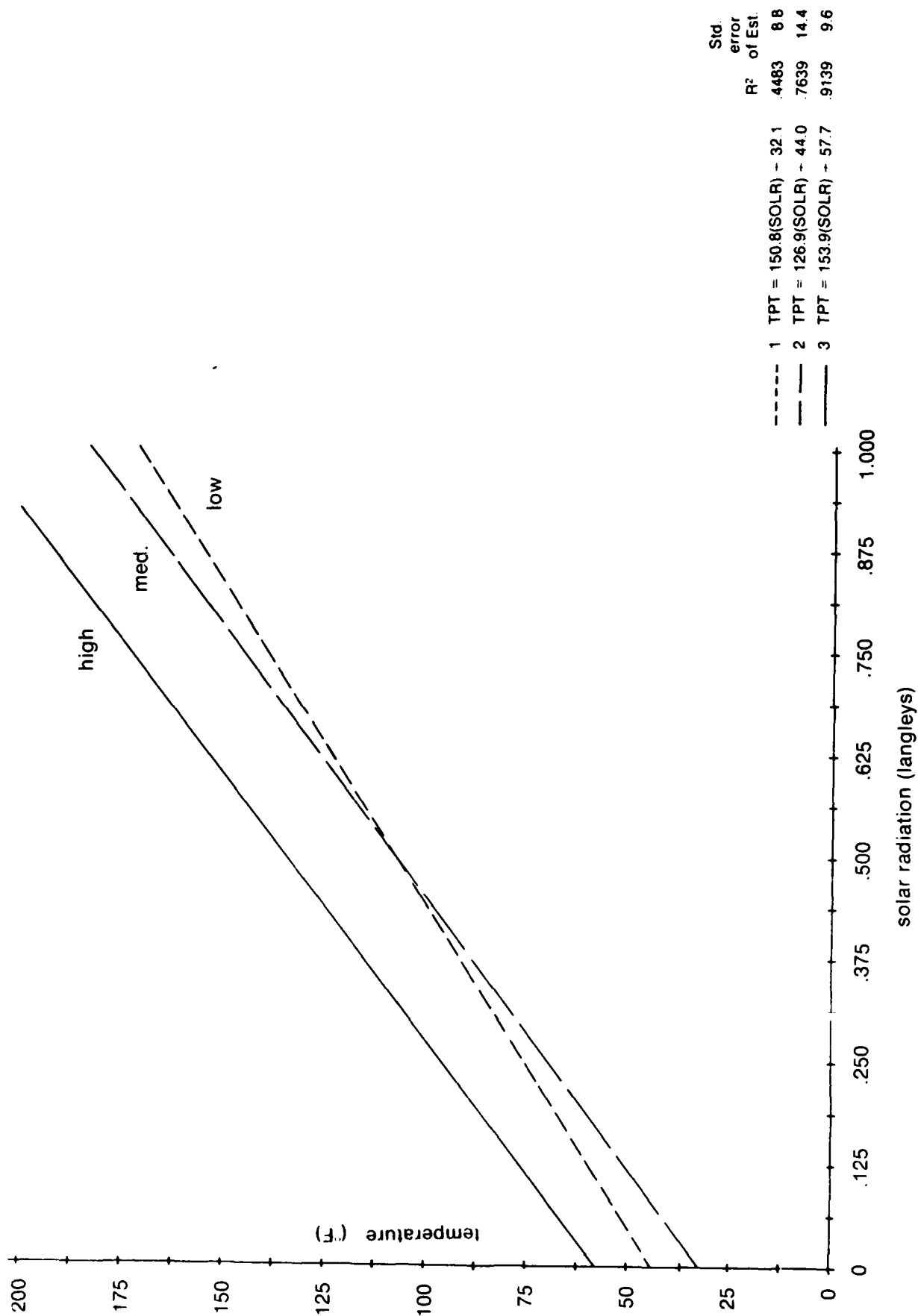


Figure 31. PUF temperature vs. solar radiation—Fort Lewis.

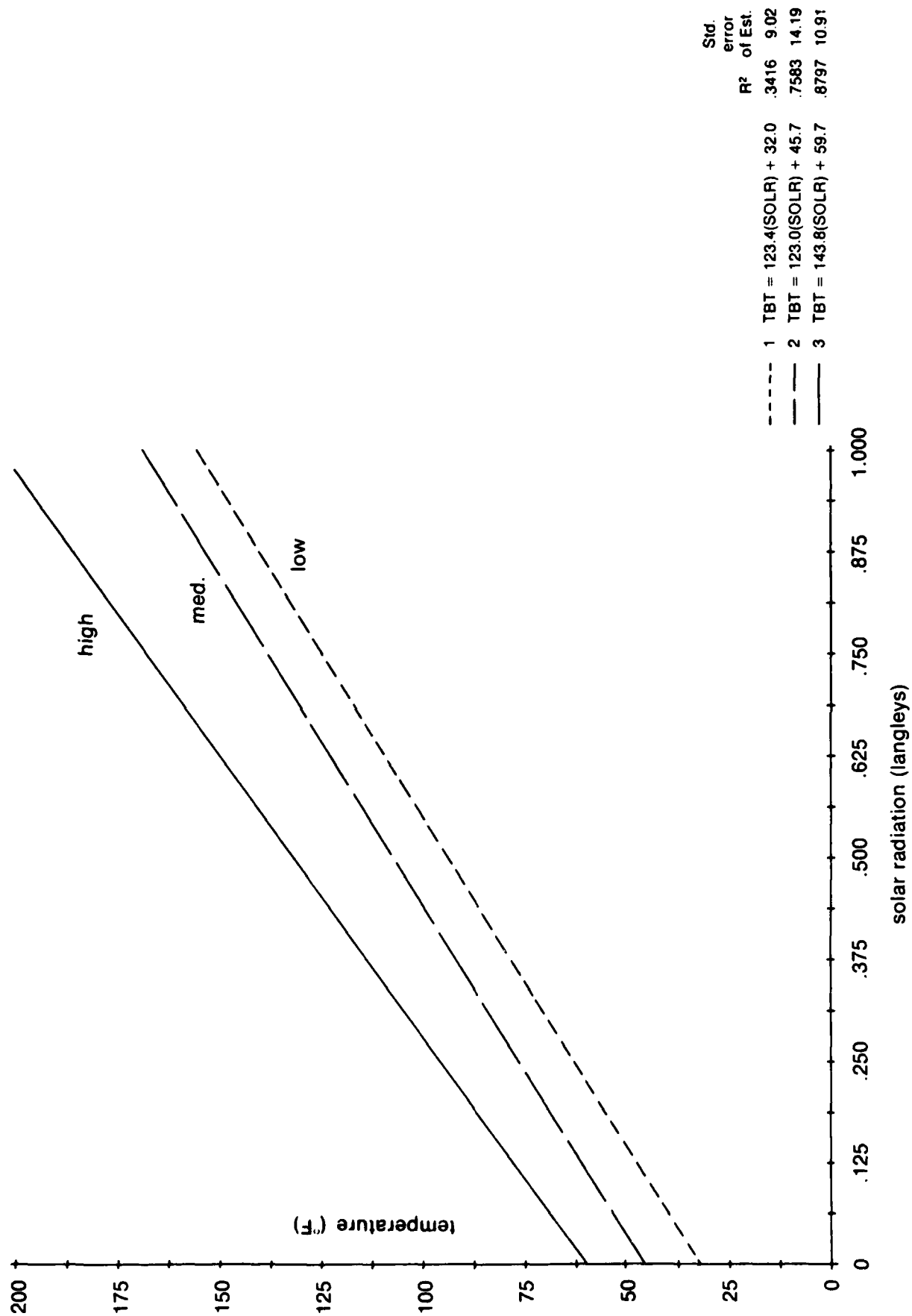


Figure 32. BUR temperature vs. solar radiation—Fort Lewis.

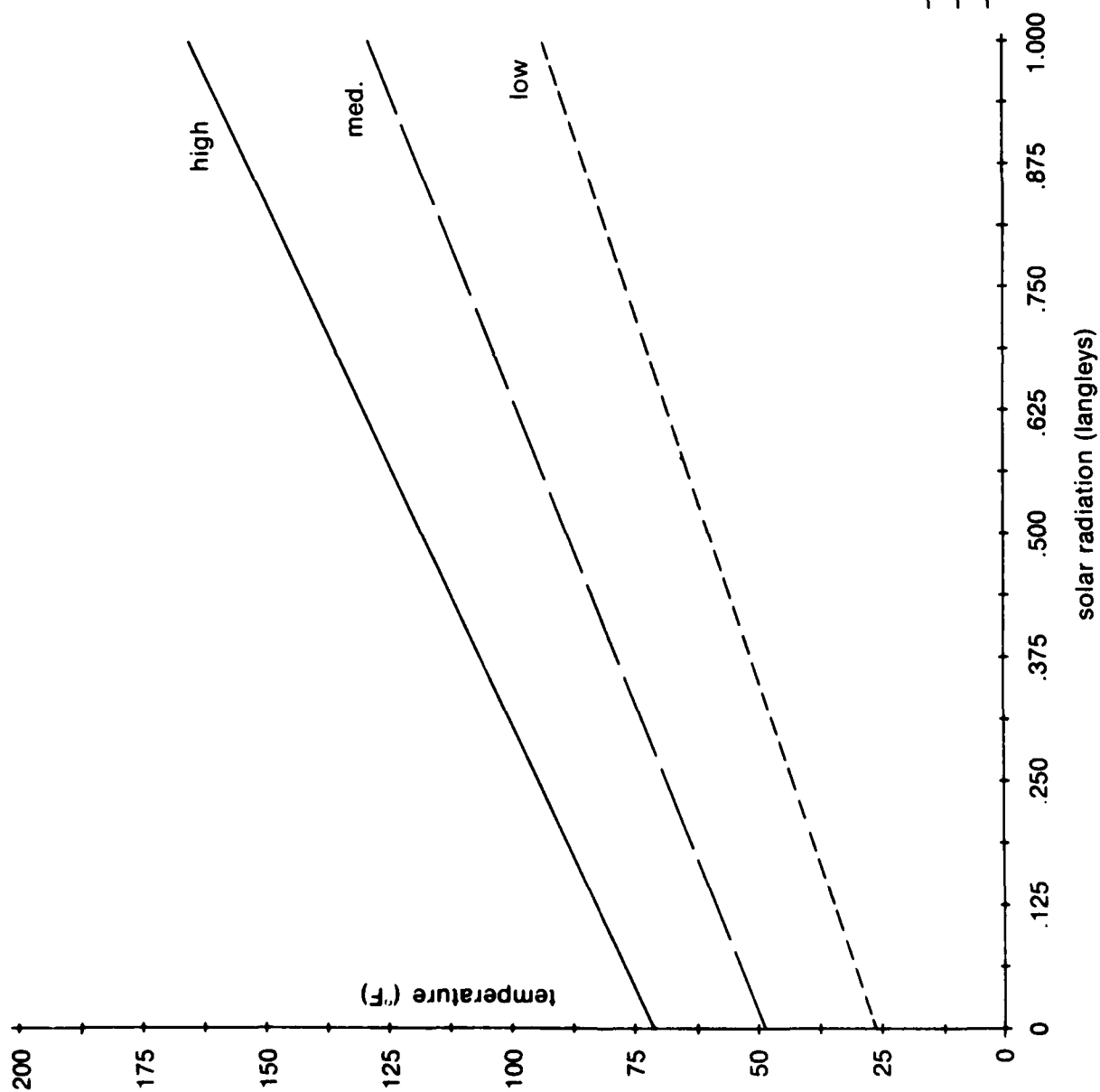


Figure 33. EPDM temperature vs. solar radiation—Fort Benning.

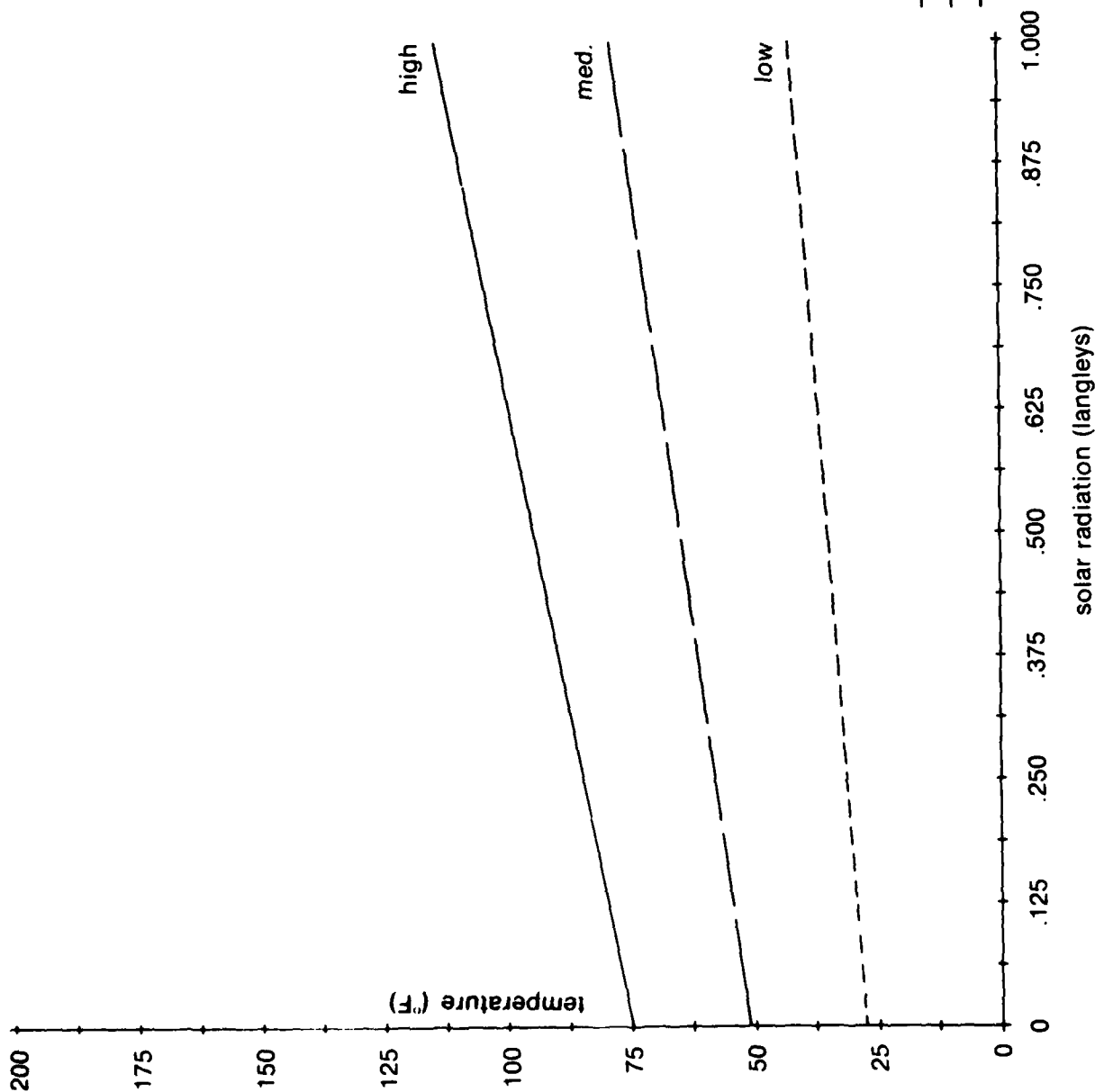


Figure 34. BUR temperature vs. solar radiation Fort Benning.



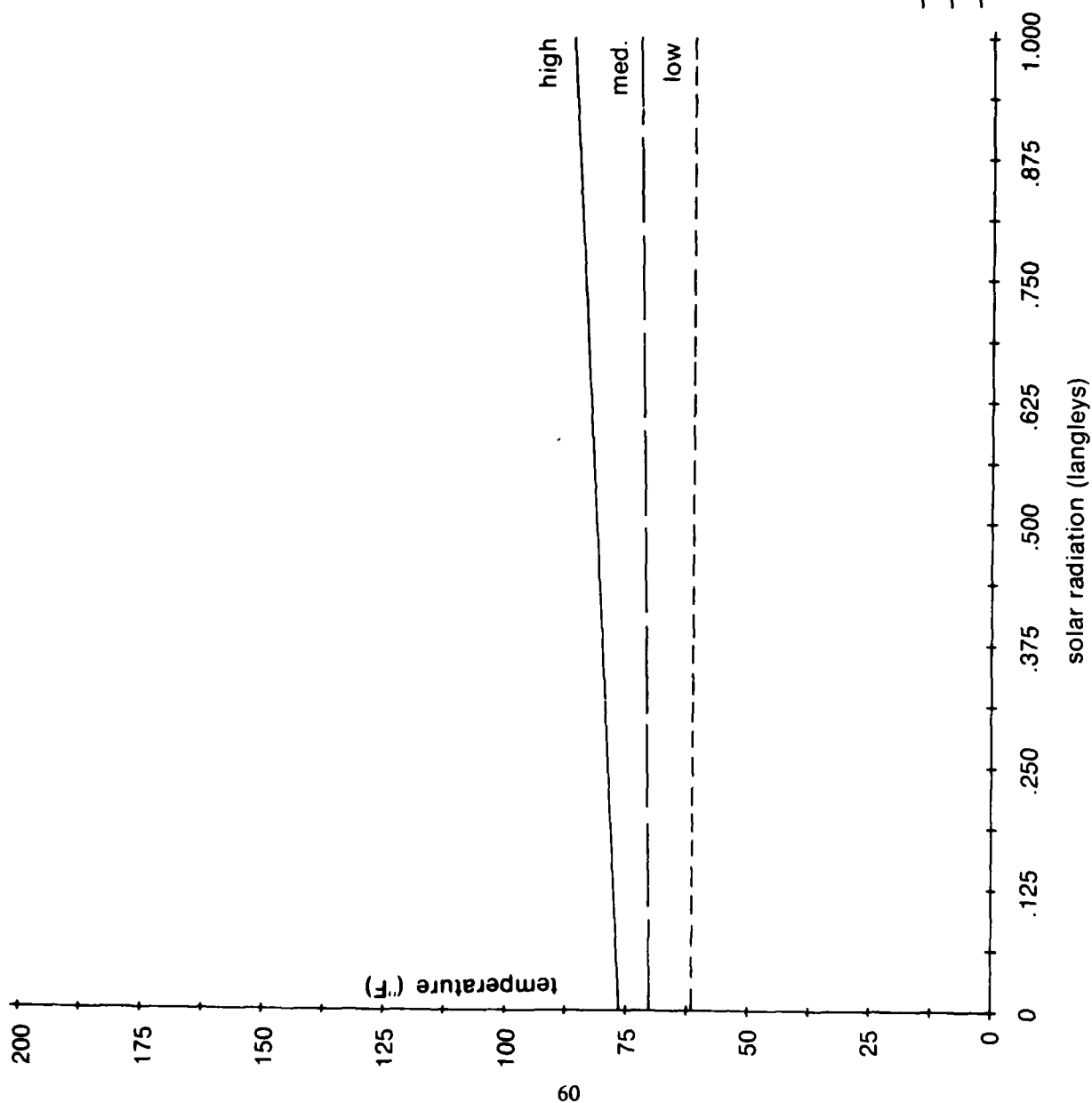
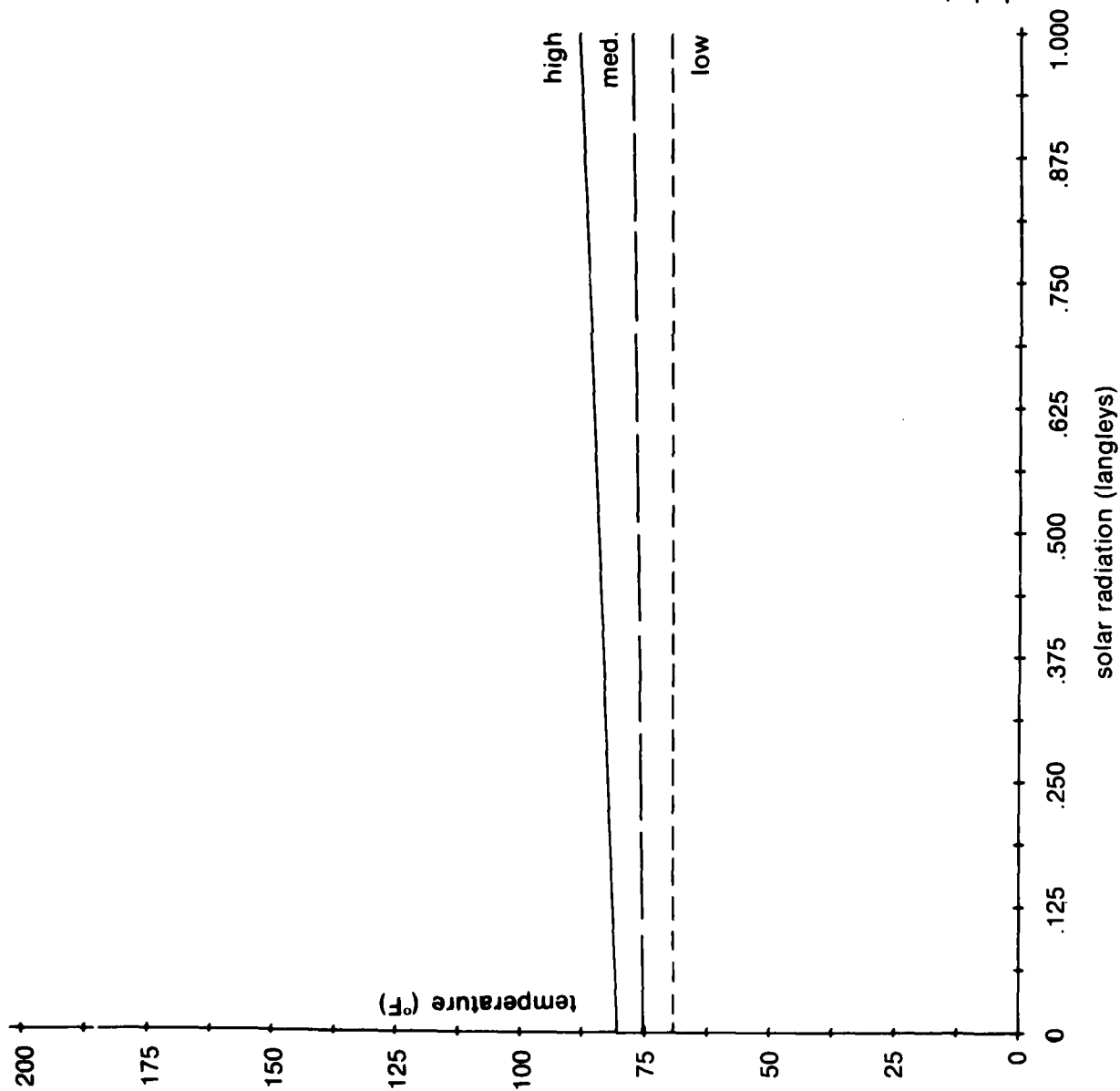


Figure 35. Deck temperature under EPDM vs. solar radiation—Fort Lewis.

		TEB =	R ²	Std. error of Est.
1	----	TEB = -.08(SOLR) + 61.52	.0001	.39
2	----	TEB = 2.3(SOLR) + 70.18	.1779	1.01
3	----	TEB = 9.9(SOLR) + 76.34	.0723	7.29



		Std. error of Est.
---	1 TPB = .94(SOLR) + 69.1	.0085 53
- - -	2 TPB = 2.7(SOLR) + 75.23	.1643 1.25
---	3 TPB = 7.9(SOLR) + 80.6	.0949 5.00

Figure 36. Deck temperature under PUF vs. solar radiation—Fort Lewis.

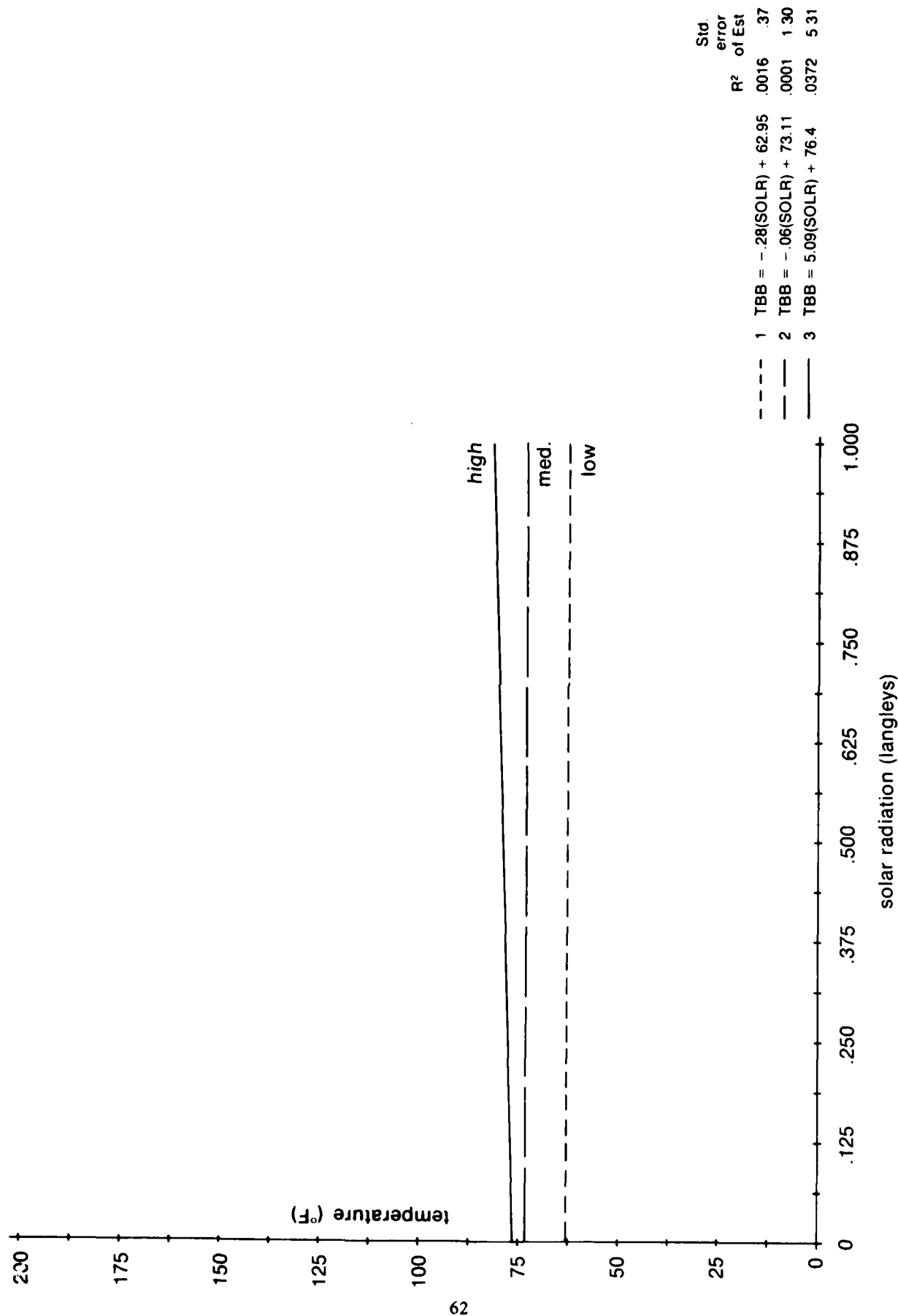
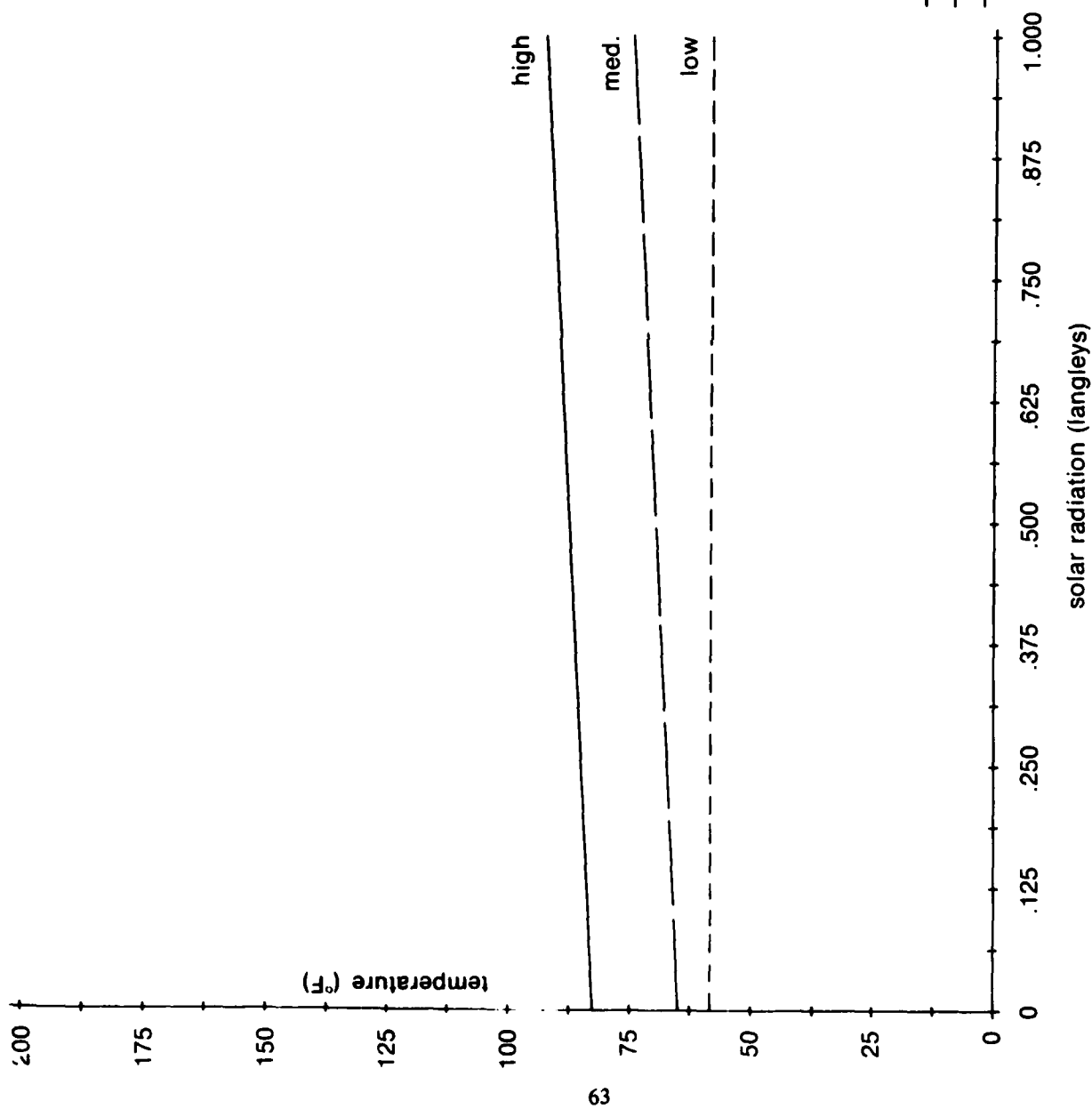


Figure 37. Deck temperature under BUR vs. solar radiation—Fort Lewis.



		TEB =	Std. error of Est.	R ² of Est.
---	1	58.26 + .265(SOLR)	.0000	10.15
- - -	2	64.81 + 10.78(SOLR)	.1311	8.90
---	3	82.63 + 9.05(SOLR)	.1770	7.97

solar radiation (langleys)

Figure 38. Deck temperature under EPDM vs. solar radiation—Fort Benning.

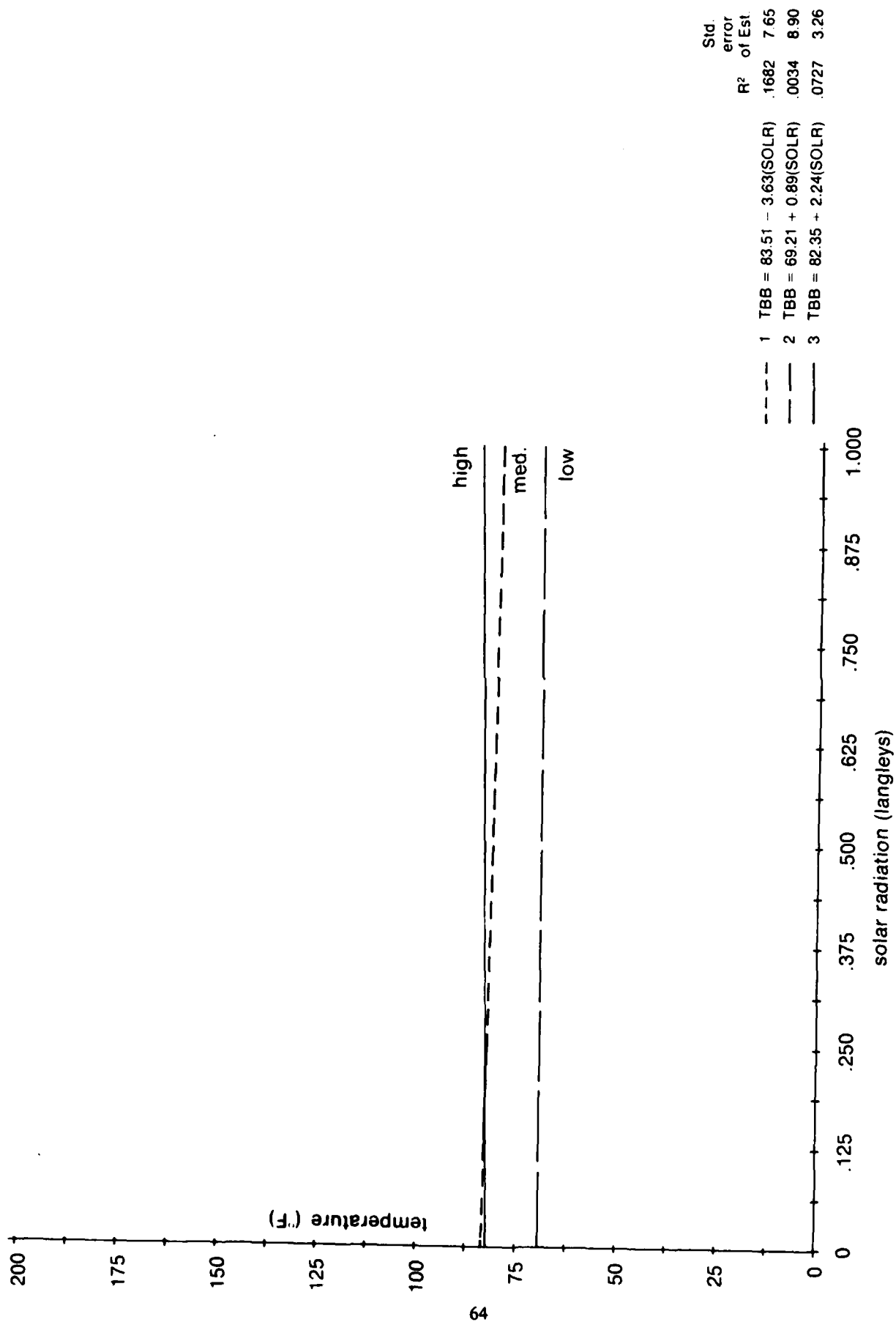


Figure 39. Deck temperature under BUR vs. solar radiation—Fort Benning.

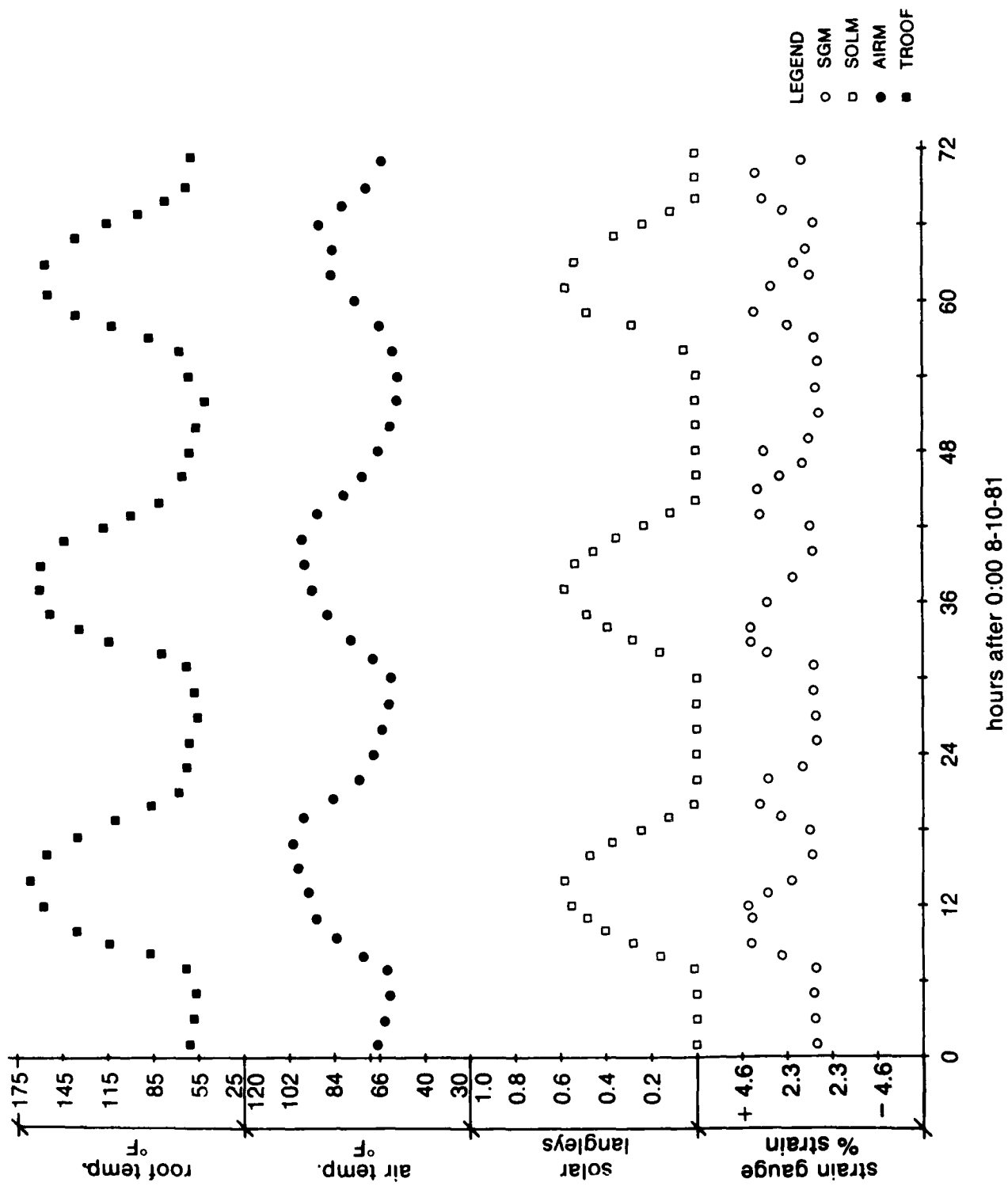


Figure 40. Parameters vs. time, high temperature and high sun—Fort Lewis, August 10–12, 1981.

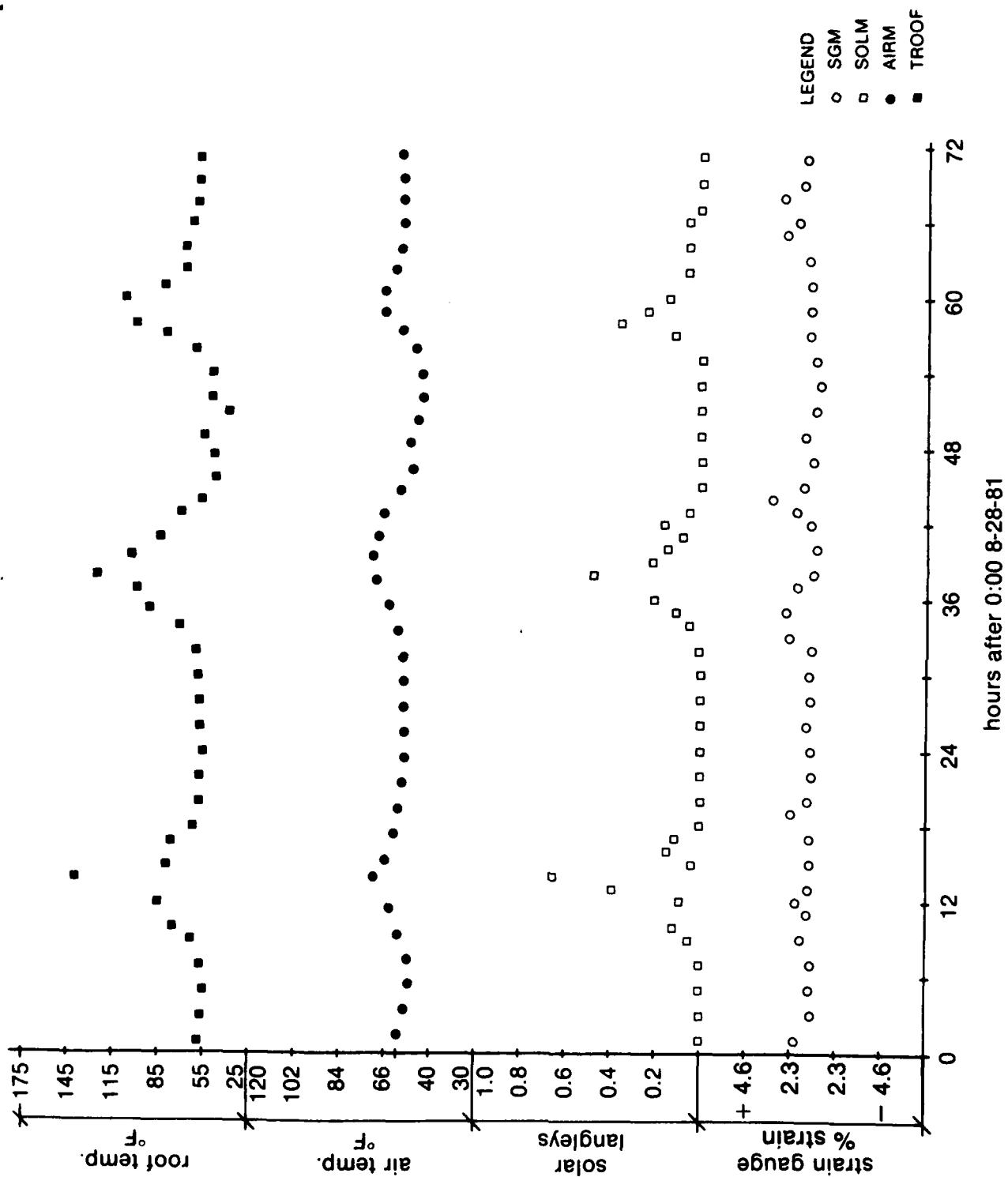


Figure 41. Parameters vs. time, high temperature and low sun—Fort Lewis, August 28–30, 1981.

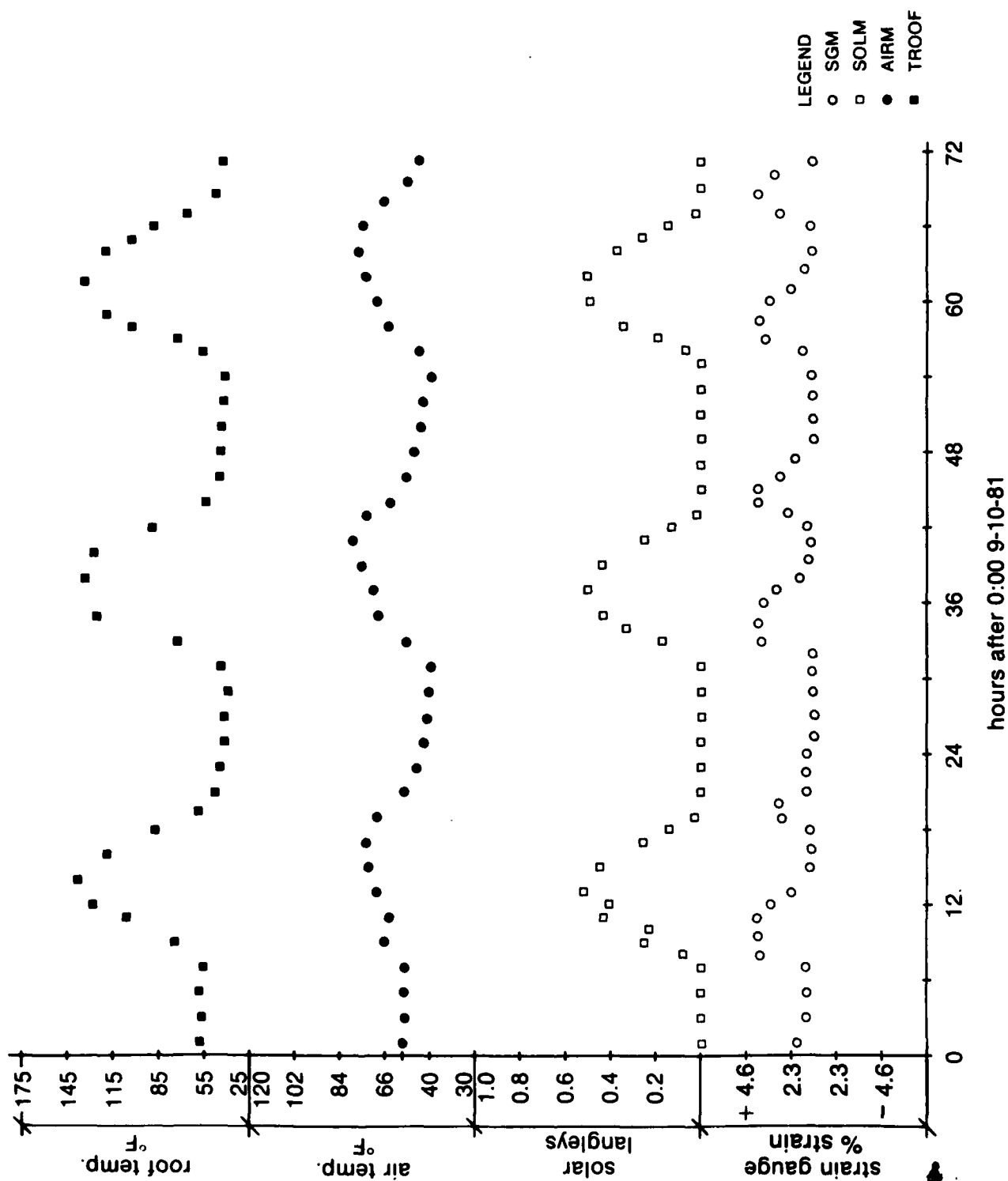


Figure 42. Parameters vs. time, low temperature and high sun—Fort Lewis, September 10–12, 1981.

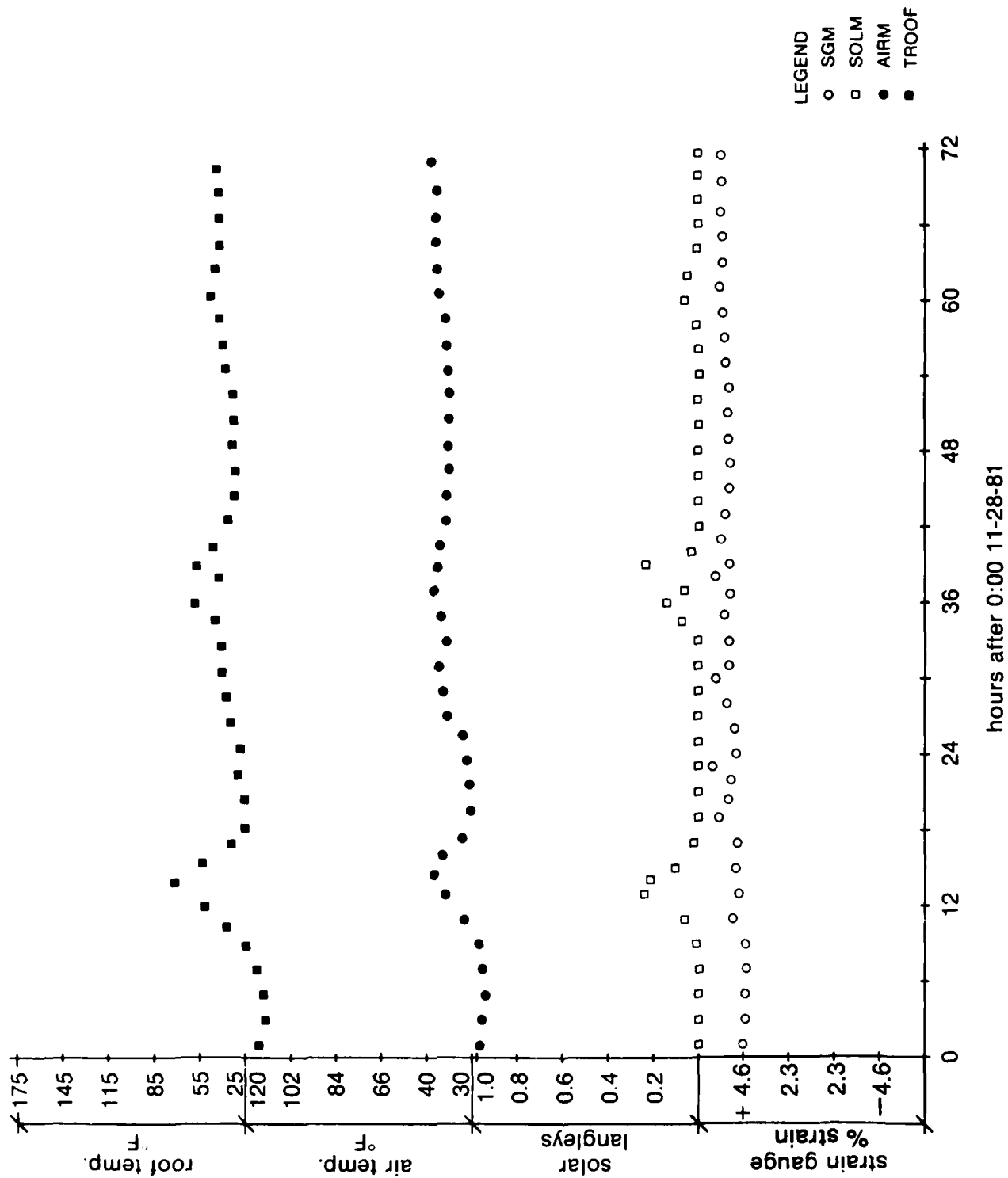


Figure 43. Parameters vs. time, low temperature and low sun—Fort Lewis, November 28–30, 1981.

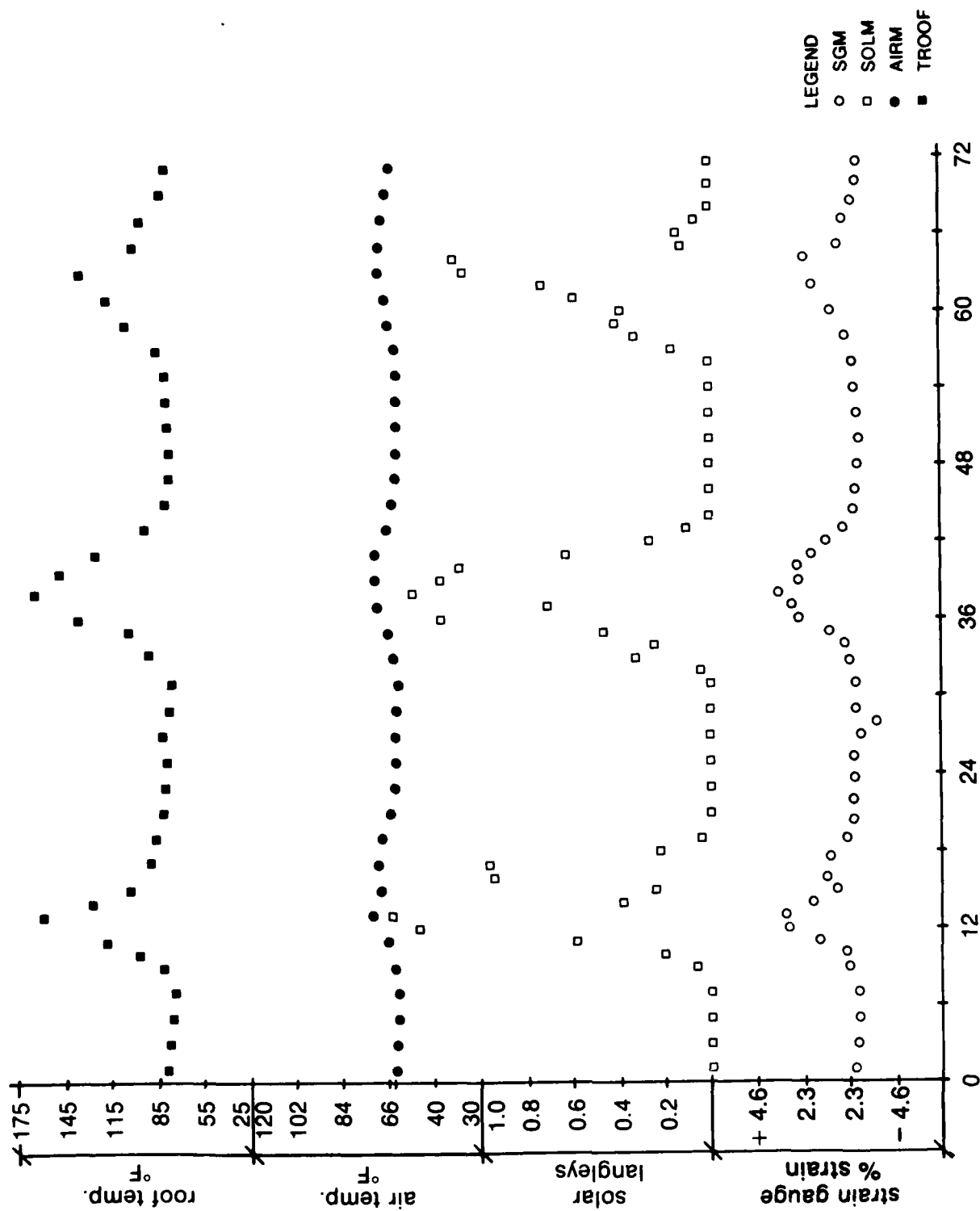


Figure 44. Parameters vs. time, high temperature and low sun—Fort Benning, September 3-5, 1981.

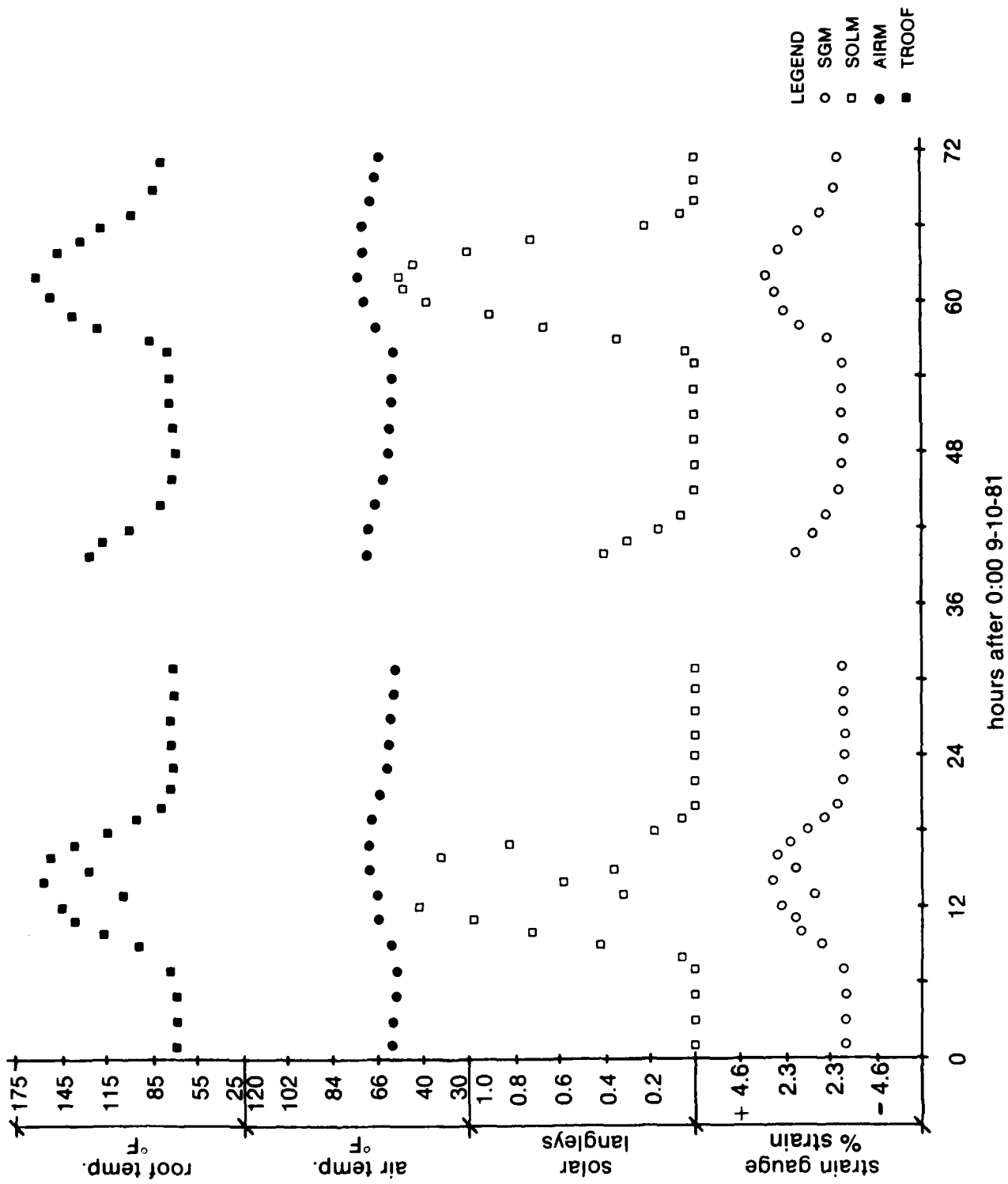


Figure 45. Parameters vs. time, high temperature and high sun - Fort Benning, September 10-12, 1981.

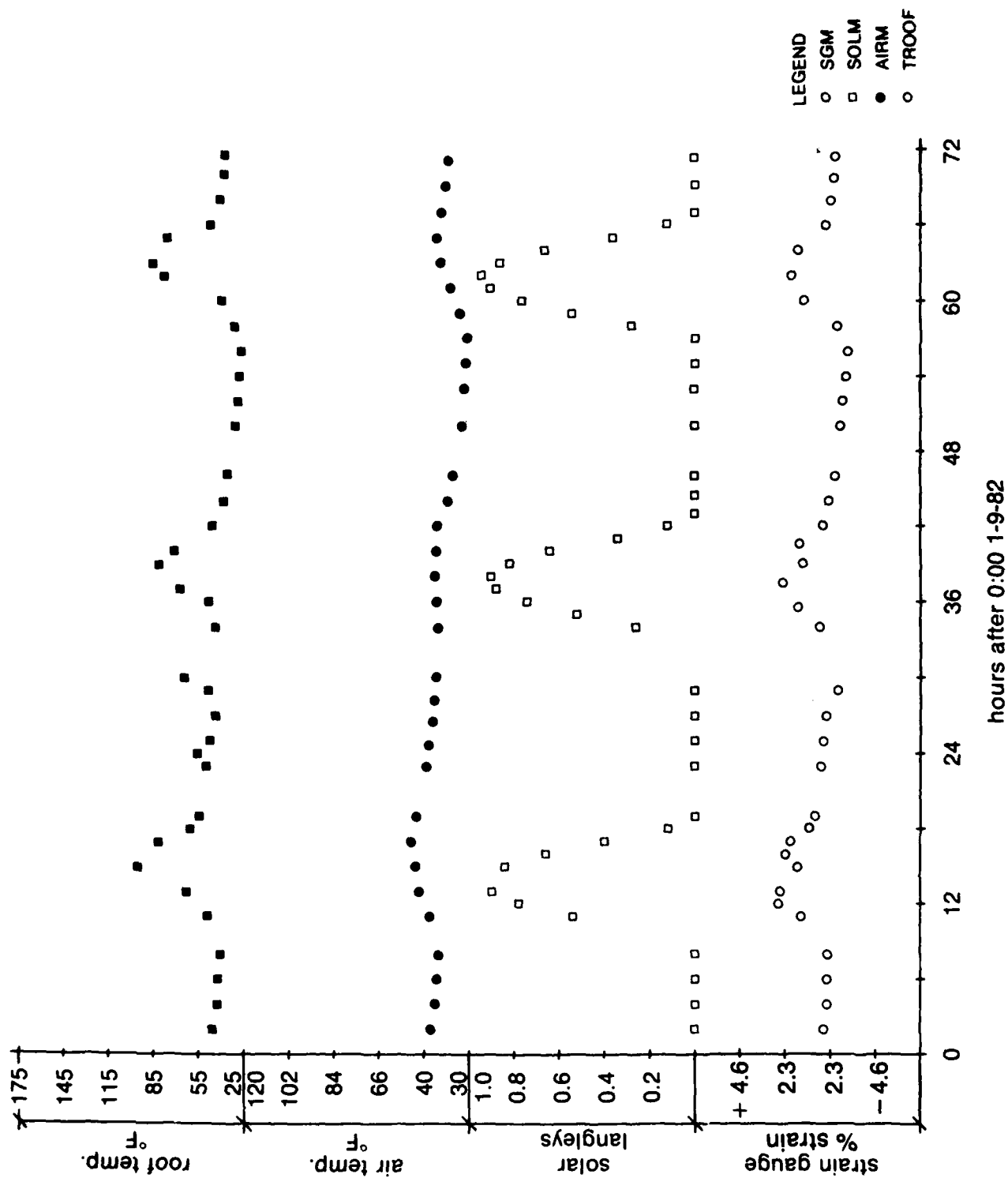


Figure 46. Parameters vs. time, low temperature and high sun—Fort Benning, January 9–11, 1982.

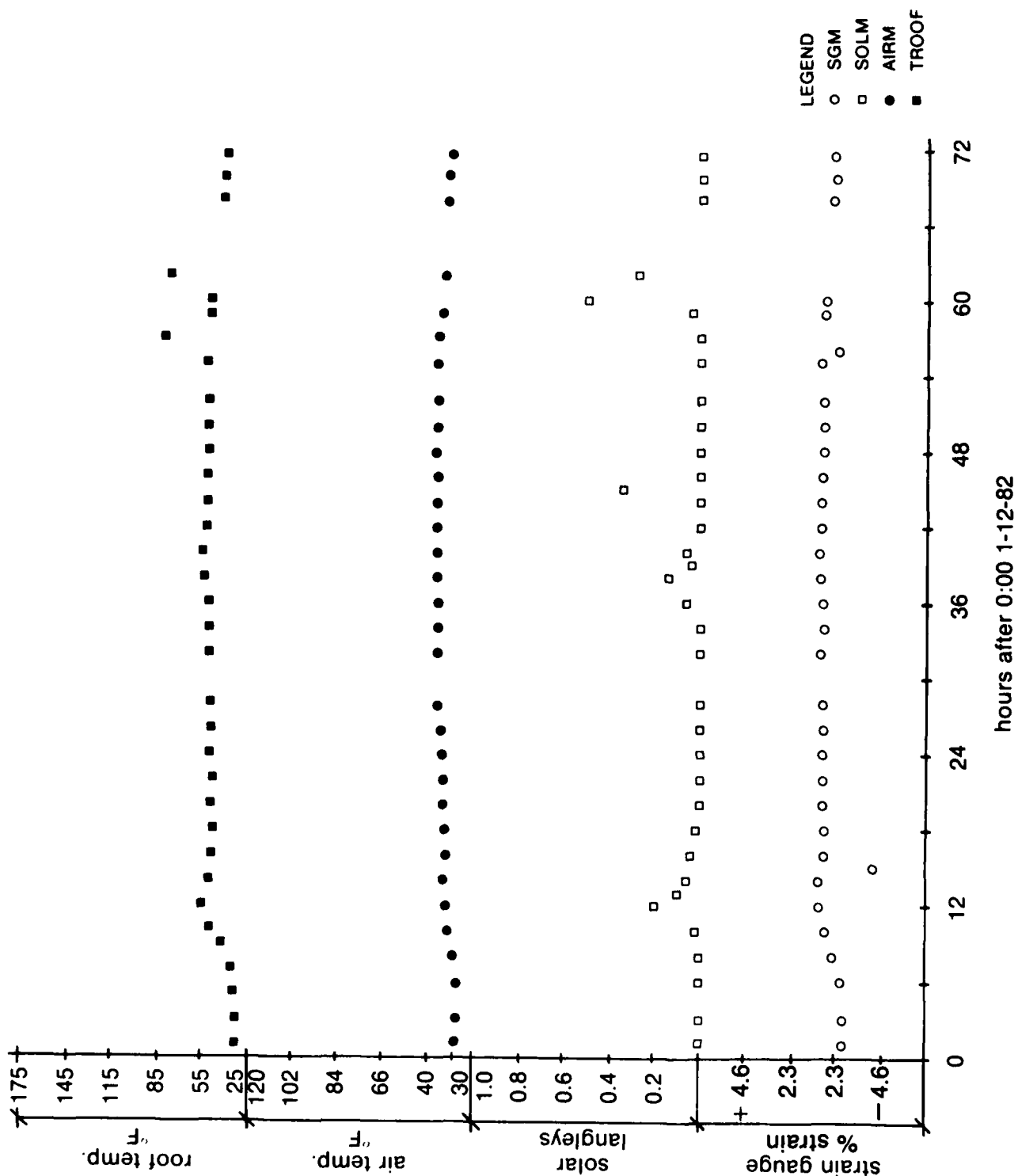


Figure 47. Parameters vs. time, low temperature and low sun—Fort Benning, January 12–14, 1982.

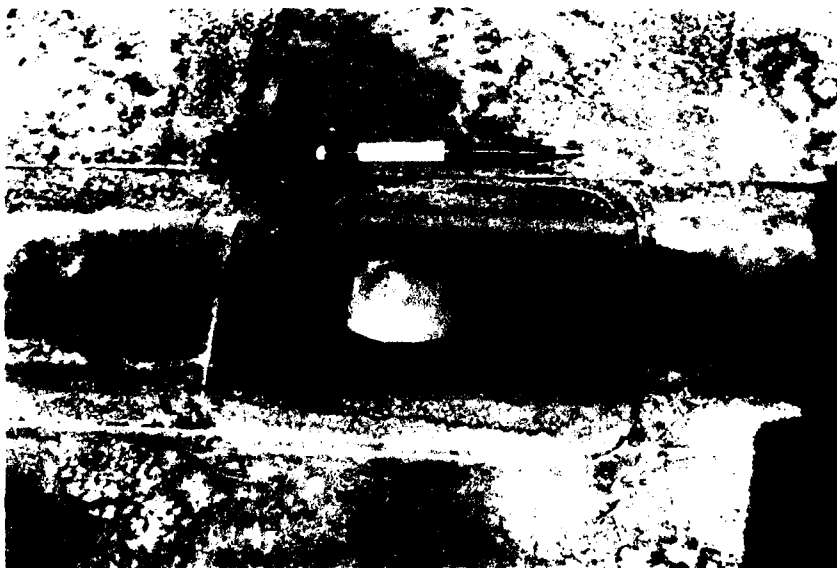


Figure 48. Blister over nail head at Fort Lewis.

CERL DISTRIBUTION

Chief of Engineers
ATTN: Tech Monitor
ATTN: DAEN-ASI-L (2)
ATTN: DAEN-CCP
ATTN: DAEN-CW
ATTN: DAEN-CWE
ATTN: DAEN-CWM-R
ATTN: DAEN-CWO
ATTN: DAEN-CWP
ATTN: DAEN-EC
ATTN: DAEN-ECC
ATTN: DAEN-ECE
ATTN: DAEN-ZCF
ATTN: DAEN-ECR
ATTN: DAEN-ED
ATTN: DAEN-RDC
ATTN: DAEN-RDM
ATTN: DAEN-EM
ATTN: DAEN-ZCZ
ATTN: DAEN-ZCE
ATTN: DAEN-ZCI
ATTN: DAEN-ZCM

FESA, ATTN: Library 22060
ATTN: DET III 79906

US Army Engineer Districts
ATTN: Library (41)

US Army Engineer Divisions
ATTN: Library (14)

US Army Europe
AEAEN-ODCS/Engr 09403
ISAE 09081

V Corps
ATTN: DEH (11)

VII Corps
ATTN: DEH (15)

21st Support Command
ATTN: DEH (12)

USA Berlin
ATTN: DEH (11)

USASETAF
ATTN: DEH (10)
Allied Command Europe (ACE)
ATTN: DEH (3)

8th USA, Korea (19)

ROK/US Combined Forces Command 96301
ATTN: EUSA-HHC-CVC/Engr

USA Japan (USARJ)
ATTN: AJEN-FE 96343
ATTN: DEH-Honshu 96343
ATTN: DEH-Okinawa 96331

Area Engineer, AEDC-Area Office
Arnold Air Force Station, TN 37389

416th Engineer Command 60623
ATTN: Facilities Engineer

US Military Academy 10966
ATTN: Facilities Engineer
ATTN: Dept of Geography &
Computer Science
ATTN: DSCPER/MAEN-A

AMMRC, ATTN: DRKMR-WE 02172

USA ARRCOM 61299
ATTN: ORCIS-RI-I
ATTN: ORSAR-IS

DARCOM - Dir., Inst., & Svcs.
ATTN: DEH (23)

DLA ATTN: DLA-WI 22314

DNA ATTN: NADS 20305

FORSCOM
FORSCOM Engineer, ATTN: APEN-DEH
ATTN: DEH (23)

HSC
ATTN: HSLO-F 78234
ATTN: Facilities Engineer
Fitzsimons AMC 80240
Walter Reed AMC 20012

INSCOM - Ch. Instl. Div.
ATTN: Facilities Engineer (3)

MDW
ATTN: DEH (3)

MTMC
ATTN: MTMC-SA 20315
ATTN: Facilities Engineer (3)

NARADCOM, ATTN: DRDNA-F 01760

TARCOM, Fac. Div. 48090

TRADOC
HQ, TRADOC, ATTN: ATEN-DEH
ATTN: DEH (19)

TSARCOM, ATTN: STSAS-F 63120

USACC
ATTN: Facilities Engineer (2)

WESTCOM
ATTN: DEH
Fort Shafter 96858
ATTN: APEN-IM

SHAPE 09055
ATTN: Survivability Section, CCB-OPS
Infrastructure Branch, LANDA

HQ USEUCOM 09128
ATTN: ECJ 4/7-LOE

Fort Belvoir, VA 22060 (7)
ATTN: Canadian Liaison Officer
ATTN: Water Resources Support Center
ATTN: Engr Studies Center
ATTN: Engr Topographic Lab
ATTN: ATZA-DTE-SU
ATTN: ATZA-DTE-EM
ATTN: R&D Command

CRREL, ATTN: Library 03755

WES, ATTN: Library 39180

HQ, XVIII Airborne Corps and
Ft. Bragg 28307
ATTN: AFZA-FE-EE

Chanute AFB, IL 61868
3345 CES/DE, Stop 27

Norton AFB CA 92409
ATTN: AFRC-EX/DEE

Tyndall AFB, FL 32403
AFESC/Engineering & Service Lab

NAFAC
ATTN: RDT&E Liaison Office (6)
ATTN: Sr. Tech. FAC-03T 22332
ATTN: Asst. CDR R&D, FAC-03 22332

NCEL 93041
ATTN: Library (Code L08A)

Defense Technical Info. Center 22314
ATTN: DDA (12)

Engineering Societies Library
New York, NY 10017

National Guard Bureau 20310
Installation Division

US Government Printing Office 22304
Receiving Section/Depository Copies (2)

US Army Env. Hygiene Agency
ATTN: HSHB-E 21010

National Bureau of Standards 20760

EMC Team Distribution

Chief of Engineers 20314
ATTN: DAEN-ZCF-B
ATTN: DAEN-ECZ-A
ATTN: DAEN-ECB (2)
ATTN: DAEN-ZCP

US Army Engineer District
New York 10007
ATTN: Chief, Design Br
Pittsburgh 15222
ATTN: Chief, ORPCD
ATTN: Chief, Engr Div
Philadelphia 19106
ATTN: Chief, NAPEN-D
Baltimore 21203
ATTN: Chief, Engr Div
Norfolk 23510
ATTN: Chief, NAOEN-M
ATTN: Chief, NAOEN-D
Huntington 25721
ATTN: Chief, ORNED-F
Wilmington 28401
ATTN: Chief, SAWCO-C
ATTN: Chief, SAWEN-D
Charleston 29402
ATTN: Chief, Engr Div
Savannah 31402
ATTN: Chief, SASAS-L
Jacksonville 32232
ATTN: Const Div
Mobile 36628
ATTN: Chief, SAMEN-D
ATTN: Chief, SAMEN-F
ATTN: Chief, SAMEN
Nashville 37202
ATTN: Chief, ORNED-F
Memphis 38103
ATTN: Chief, Const Div
ATTN: Chief, LMED-D
Vicksburg 39180
ATTN: Chief, Engr Div
Louisville 40201
ATTN: Chief, Engr Div
Detroit 48231
ATTN: Chief, NCEED-T
St. Paul 55101
ATTN: Chief, ED-D
ATTN: Chief, ED-F
Chicago 60604
ATTN: Chief, NCCCO-C
ATTN: Chief, NCCED-F
Rock Island 61201
ATTN: Chief, Engr Div
ATTN: Chief, NCREG-F
St. Louis 63101
ATTN: Chief, ED-D
Kansas City 64106
ATTN: Chief, Engr Div
Omaha 68102
ATTN: Chief, Engr Div
New Orleans 70160
ATTN: Chief, LMED-DG
Little Rock 42203
ATTN: Chief, Engr Div
Tulsa 74102
ATTN: Chief, Engr Div
Ft. Worth 76102
ATTN: Chief, SWFED-D
ATTN: Chief, SWFED-F
Galveston 77550
ATTN: Chief, SWGAS-L
ATTN: Chief, SWGCO-C
ATTN: Chief, SWGED-DC
Albuquerque 87103
ATTN: Chief, Engr Div
Los Angeles 90053
ATTN: Chief, SPLED-F
San Francisco 94105
ATTN: Chief, Engr Div
Sacramento 95814
ATTN: Chief, SPKED-D
ATTN: Chief, SPKCO-C
Far East 96301
ATTN: Chief, Engr Div

US Army Engineer District
Portland 97208
ATTN: Chief, DB-6
ATTN: Chief, FM-1
ATTN: Chief, FM-2
Seattle 98124
ATTN: Chief, NPSCO
ATTN: Chief, NPSEN-FM
ATTN: Chief, EN-DB-ST
Walla Walla 99362
ATTN: Chief, Engr Div
Alaska 99501
ATTN: Chief, NPASA-R

US Army Engineer Division
New England 02154
ATTN: Chief, NEDED-T
ATTN: Laboratory
ATTN: Chief, NEDCO
Middle East (Rear) 22601
ATTN: Chief, MEDED-T
North Atlantic 10007
ATTN: Chief, NADEN
South Atlantic 30303
ATTN: Laboratory
ATTN: Chief, SADEN-TC
ATTN: Chief, SADEN-TS
Huntsville 35807
ATTN: Chief, HNDED-CS
ATTN: Chief, HNDED-M
ATTN: Chief, HNDED-SR
Lower Mississippi 39180
ATTN: Chief, LMVED-G
Ohio River 45201
ATTN: Laboratory
ATTN: Chief, Engr Div
Missouri River 68101
ATTN: Chief, MRDED-G
ATTN: Laboratory
Southwestern 75202
ATTN: Laboratory
ATTN: Chief, SWDED-MA
ATTN: Chief, SWDED-TG
South Pacific 94111
ATTN: Laboratory
Pacific Ocean 96858
ATTN: Chief, Engr Div
ATTN: FM&S Branch
ATTN: Chief, PODED-D
North Pacific 97208
ATTN: Laboratory
ATTN: Chief, Engr Div

6th US Army 94129
ATTN: AFKC-EN

7th US Army 09407
ATTN: AETTM-HRD-EHD

HQ, Combined Field Army (ROK/US) 96358
ATTN: CFAR-EN

HQDA SGRD-EDE 20314

US Army Foreign Science and
Tech Center
ATTN: Charlottesville, VA 22901
ATTN: Far East Office 96328

USA ARRADCOM 07801
ATTN: ORDAR-LCA-OK

HQ, USAMRDC
ATTN: SGRD-PLC
Fort Detrick, MD 21701

West Point, NY 10996
ATTN: Dept of Mechanics
ATTN: Library

Ft. Belvoir, VA 22060
ATTN: ATSE-TD-TL (2)
ATTN: Learning Resource Center
ATTN: British Liaison Officer (5)

Ft. Benning, GA 31905
ATTN: ATZB-FE-EP
ATTN: ATZB-FE-BG

Ft. Clayton Canal Zone 34004
ATTN: DFAE

Ft. Leavenworth, KS 66027
ATTN: ATZLCA-SA

Ft. Lee, VA 23801
ATTN: DRXMC-D (2)

Ft. McPherson, GA 30330
ATTN: AFEN-CD

Ft. Monroe, VA 23651
ATTN: ATEN-AD (3)
ATTN: ATEN-FE-ME
ATTN: ATEN-FE-EN (2)

Ft. Richardson, AK 99505
ATTN: AFZT-FE-E

Rocky Mountain Arsenal 80022
ATTN: SARRM-CO-FEP

USA-WES 39180
ATTN: C/Structures
ATTN: Soils & Pavements Lab

Naval Facilities Engr Command 22332
ATTN: Code 04
ATTN: Code 2013 C

Port Hueneme, CA 93043
ATTN: Merrill Library

Commander (Code 2636) 93555
Naval Weapons Center

Bolling AFB, DC 20332
AF/LEEU

Little Rock AFB
ATTN: 314/DEEE

Patrick AFB, FL 32925
ATTN: XRQ

Tinker AFB, OK 73145
2854 ABG/DEEE

Tyndall AFB, FL 32403
AFESC/TST

Airports and Const Services Dir
Technical Info Reference Center
Ottawa, Ontario, Canada K1A 0N8

Bldg Research Advisory Board 20418
Federal Aviation Administration 20540
Dept of Transportation Library 20590
Transportation Research Board 20418

Division of Building Research
National Research Council
Ottawa, Ontario, Canada K1A 0R6

National Defense Headquarters
Director General of Construction
Ottawa, Ontario, Canada K1A 0K2

Rosenfield, Myer J.

Field test results of experimental EPDM and PUF roofing. - Champaign, ILL :
Construction Engineering Research Laboratory , 1984.
73 p. (Technical report ; M-357)

1. Roofs. 2. Ethylene - propylene - diene - monomer (EPDM). 3. Poly-
urethane foam (PUF). I. Title. II. Series ; Technical report (Construction
Engineering Research Laboratory) ; M-357.

END

FILMED

1-85

DTIC